GESTÃO & PRODUÇÃO

ISSN 0104-530X (Print)
ISSN 1806-9649 (Online)

THEMATIC SECTION

Digital Transformation, Intelligent Manufacturing and Supply Chain Management 4.0

Selection of additive manufacturing technologies in productive systems: a decision support model

Seleção de tecnologias de manufatura aditiva em sistemas produtivos: modelo de apoio à decisão

Douglas Rhoden Calderaro[1], Daniel Pacheco Lacerda[2], Douglas Rafael Veit[2]

[1]Universidade do Vale do Rio dos Sinos – UNISINOS, Programa de Pós-graduação em Engenharia de Produção e Sistemas, São Leopoldo, RS, Brasil. E-mail: douglasrhodencalderaro@outlook.com

[2]Universidade do Vale do Rio dos Sinos – UNISINOS, Programa de Pós-graduação em Engenharia de Produção e Sistemas, Grupo de Pesquisa em Modelagem para Aprendizagem – GMAP, São Leopoldo, RS, Brasil. E-mail: dlacerda@unisinos.br; douglasveit@unisinos.br

How to cite: Calderaro, D. R., Lacerda, D. P., & Veit, D. R. (2020). Selection of additive manufacturing technologies in productive systems: a decision support model. *Gestão & Produção*; 27(3), e5363. https://doi.org/10.1590/0104-530X5363-20

Abstract: Additive Manufacturing (AM) has seen continued growth in adoption by organizations in recent years, changing production processes, supply chain, maintenance, product development and the global economy. There are several Additive Manufacturing technologies and equipment on the market, however, there are no guidelines, benchmarking or decision support tools for proper selection. After a systematic review of the literature, the lack of propositions that act during the development of the product and process was evidenced. This research focuses on the selection of Additive Manufacturing technologies for a production system. The general objective being to propose a decision support model based on the characteristics of additive technologies and competitive criteria, resulting in a choice aligned with the guidelines of organizations and their production systems. For the operationalization of the model, the AHP techniques and conjoint analysis were used together, where the characteristics of the Additive Manufacturing technologies were related to the competitive criteria for the model to indicate the recommended technology to the production system or organization in question. Finally, the artifact recommended the right technology in three distinct situations, from a vendor, user, and expert point of view. Thus, this research contributes to both academia and business by developing a functional artifact of additive manufacturing technology selection. Also, by contributing to the increased availability of information on the nine most commonly used additive technologies in industry.

Keywords: Additive Manufacturing; Competitive criteria; Production systems; Conjoint analysis; Analytic Hierarchy Process.

Resumo: A Manufatura Aditiva (AM) vem apresentando crescimento contínuo de adoção por parte das organizações nos últimos anos, modificando os processos produtivos, cadeia de suprimentos, manutenção, desenvolvimento de produto e a economia global. Há no mercado, diversas tecnologias de Manufatura Aditiva e equipamentos para utilização, contudo, não há diretrizes, *benchmarking* ou ferramentas de suporte à decisão quanto à seleção adequada. Após a revisão sistemática da literatura, evidenciou-se a falta de proposições que atuam durante o desenvolvimento do produto e processo. Esta pesquisa tem como questão central, a seleção de

Received Feb. 24, 2019 - Accepted Nov. 24, 2019
Financial support: None.

tecnologias de Manufatura Aditiva para um sistema produtivo. Sendo o objetivo geral propor um modelo de apoio à tomada de decisão baseado nas características das tecnologias aditivas e nos critérios competitivos, resultando assim, em uma escolha alinhada às diretrizes das organizações e dos seus sistemas produtivos. Para a operacionalização do modelo, as técnicas AHP e análise conjunta foram utilizadas de maneira integrada, onde as características das tecnologias de Manufatura Aditiva foram relacionadas com os critérios competitivos, para que o modelo indicasse a tecnologia recomendada ao sistema produtivo ou organização em questão. Por fim, o artefato recomendou a tecnologia adequada em três situações distintas, sob ponto de vista do fornecedor, usuário e especialista. Desta forma, esta pesquisa contribui tanto para o meio acadêmico quanto ao empresarial, ao desenvolver um artefato funcional de seleção de tecnologia de Manufatura Aditiva. E também, ao contribuir para o aumento da disponibilidade de informações relativas às nove tecnologias aditivas mais comumente utilizadas na indústria.

Palavras-chave: Manufatura Aditiva; Critérios competitivos; Sistemas produtivos; Análise conjunta; Análise Hierárquica de Processos (AHP).

1 Introduction

"Industrial production is currently driven by global competition and the needs for fast adaptation of production [...] and these requirements can be met by radical advances in traditional manufacturing technology" (Rojko, 2017, p. 77). With regard to Additive Manufacturing, over the last 20 years, technologies have migrated from rapid prototyping to direct digital manufacturing (Crump, 2016). In this evolutionary scenario, where hardware and software combine, there is the constantly dissemination of new Additive Manufacturing technologies (Cochet, 2016; Park, 2017). Additive Manufacturing can change aspects of production, supply chain, maintenance, product development and global economy, in addition, there has been a growing interest on the part of the companies regarding the increase of efficiency and productivity (Ben-Ner & Siemsen, 2017; Ernst & Young GmbH, 2016; Pacheco et al., 2014; Piran et al., 2017).

The use of Additive Manufacturing by organizations is growing and one of the reasons is that companies that adopt AM technologies are getting an increase in their return on investment (Sculpteo, 2017). This is due to the high degree of efficiency, accuracy and functionality offered by AM technologies, allowing to manufacture complex parts, which were previously not possible in traditional production systems supported by subtractive technologies. (Cochet, 2016; Gokuldoss et al., 2017). In addition, in dynamic and highly competitive environments, it makes companies to structure themselves more effectively to enable the commercialization of products and services with better effectiveness constantly (Dresch et al., 2019; Veit et al., 2017).

Additive Manufacturing technologies are enabling, within the framework of production systems, new paradigms regarding manufacturing options (Paris et al., 2016). AM is no longer used only for prototypes and is now used for direct production, i.e. in the manufacture of functional parts of final products (Persons, 2015). However, each AM technology has advantages and disadvantages that may be suitable, or not, depending on the competitive criteria prioritized in the production system under analysis, being one of the reasons why the technology should be technically selected. Additive Manufacturing technologies have divergent aspects, which aligned to the lack of benchmarking standards and the lack of experience by the organizations makes selecting AM technology complex (Park & Tran, 2017).

In summary, the high amount of AM technologies and divergent aspects between them turn the decision-making process complex and difficult for the organizations. In addition, the lack of information and comparability tools raise the risks of capital investment for companies and also contribute to the selection process and consequent decision being arduous. Additionally, the variability of organizations' strategies to maintain their relevance towards competitors and consumers, as well as to meet market requirements, requires a constant adaptation of production systems. In which, besides to the production system being able to meet engineering specifications, it must be able to adapt to manufacture new products efficiently. One way is to align the strategy outlined by the company, for this, it is necessary to meet the competitive criteria prioritized by the organization. Given this context, the central issue of this work emerges: **How to select an Additive Manufacturing technology for a production system?**

The general objective derived from this research issue is the proposition of a model to support decision-making based on the characteristics of additive technologies and competitive criteria for the selection of Additive Manufacturing technologies in production systems. So, the specific objectives are the comparative analysis of AM technologies and the presentation of an AHP integration with Conjoint Analysis to support decision-making to select AM technology.

This article is structured in seven sections. The first one presents the theme, object and problem of this research. Where, it contextualizes, relevant data to work are approached and presents the theoretical context in which this work is inserted and that intends to contribute. The second section refers to the theoretical framework. In which it'll be adressed concepts and characteristics about Additive Manufacturing and some of the AM technologies, in addition to productive systems, competitive criteria and aspects related to the selections of technologies. The third part refers to the research methodology. The fourth section refers to the proposition and development of the artifact of this research. Where, the artifact construction process, functionality and interface are detailed. Including the process on statistics (AHP and Conjoint Analysis), in addition to the dynamics between the two techniques. The fifth part presents the results found regarding the three distinct situations (real decision maker, supplier and expert). Finally, in the sixth chapter the results are discussed, and in the seventh the final considerations of the research, limitations and suggestions for future research are disclosed.

2 Theoretical framework

In this section will be presented the theoretical framework used for the development of this research. The concepts covered are: productive systems, Additive Manufacturing and its technologies, competitive criteria and selection of technologies for manufacturing.

2.1 Additive manufacturing

Additive Manufacturing is a set of technologies that manufactures three-dimensional objects from digital models through the process of adding material, these materials can be metals, ceramics, polymers, among others (Ford, 2014; ISO, 2016). The mass admission of Additive Manufacturing technologies will change the future of organizations, whether in aspects relating to supply chain, production, maintenance, global economy, among others (Ben-Ner & Siemsen, 2017).

The ISO/ASTM 52900 Standard ranks Additive Manufacturing technologies into 7 classes, which are: *Binder Jetting, Directed Energy Deposition, Material Extrusion, Material Jetting, Powder Bed Fusion, Sheet Lamination and Vat Photopolymerisation*. Table 1 displays the technologies covered and their respective classes according to ISO/ASTM 52900 (ISO, 2016).

Table 1. Classification of Additive Manufacturing Technologies.

Additive Manufacturing Classification as ISO/ASTM 52900	AM technologies covered in this article
Binder Jetting	*Binder Jetting* (BJ)
Directed Energy Deposition	*Laser Engineering Net Shape* (LENS)
Material Extrusion	*Fused Deposition Modeling* (FDM)
Material Jetting	*Material Jetting* (MJ)
Powder Bed Fusion	*Electron Beam Melting* (EBM)
	Selective Laser Sintering (SLS)
	Selective Laser Melting (SLM)
Sheet Lamination	*Laminated Object Manufacturing* (LOM)
Vat Photopolymerisation	*Stereolithography* (SLA)

Source: Prepared by authors based on 3D Hubs (2016).

Among the various additive manufacturing technologies found in the systematic review of literature, 9 technologies were selected. The selection criterion used was the number of articles found in the literature review dealing with the AM technology evidenced and also because they are the same additive technologies referenced as the most popular in the industry (3D Hubs, 2016; 3D Insider, 2017; Redwood, 2017).

Furthermore, Table 2 lists the disadvantages and advantages in relation to characteristics commonly used by the authors found during the systematic review of the literature. For the classification of “Advantage” it was used the “+” signal and for the classification of “Disadvantage” the signal of “-” was used. Post processing is understood as stages/treatments to improve surface quality, precision, mechanical/thermal properties, among others. Regarding cost, the same order of magnitude of the authors seen in this section was used.

Where, they used the same comparative criteria, the information came from a previous analysis of these authors. A total of 45 positive aspects and 36 negative aspects stand out. In the next section, the competitive criteria and their relationship with Additive Manufacturing will be presented.

Table 2. Characteristics of Additive Manufacturing Technologies.

Description	Material Jetting (MJ)	Electron Beam Melting (EBM)	Laser Engineering Net Shape (LENS)	Selective Laser Sintering (SLS)	Stereolithography (SLA)	Binder Jetting (BJ)	Selective Laser Melting (SLM)	Fused Deposition Modeling (FDM)	Laminated Object Manufacturing (LOM)
Manufacturing Time	+	-	+	-	+	+	-	+	+
Surface Quality	+	+	-	-	+	-	-	-	-
Mechanical Properties	+	+	+	+	-	-	+	-	-
Thermal Properties	+	+	+	+	-	-	+	-	-
Complexity of parts	+	+	+	+	+	+	+	+	-
Manufacturing Dimensions	+	-	+	+	+	+	-	+	-
Precision	+	+	-	+	+	+	+	-	-
Post Processing	-	-	-	-	-	-	-	-	+
Operation Cost	-	-	+	-	-	+	+	+	+
Bibliographical References Advantages (+)	(Additively, 2017c; Calignano et al., 2017; Redwood et al., 2017; Varotsis, 2017).	(GmbH, 2013; Hiemenz, 2007; Redwood, 2017)	(Bikas et al., 2016; Huang et al., 2013a; Mahamood et al., 2014; Mudge & Wald, 2007; Srivatsan & Sudarshan, 2015; Zhai et al., 2014)	(Chen et al., 2016; Mahamood et al., 2014; Redwood., 2017)	(Mahamood et al., 2014; Redwood et al., 2017)	(Additively, 2017a; ExOne, 2017; Gokuldoss et al., 2017; Malladi, 2017; Redwood et al., 2017)	(Additively, 2017d; Gokuldoss et al., 2017; Redwood et al., 2017; Yasa & Kruth, 2011)	(Bikas et al., 2016; Calignano et al., 2017; Mahamood et al., 2014; Peleshenko et al., 2017; Redwood et al., 2017)	(Mahamood et al., 2014; Pilipovic et al., 2011; Wong & Hernandez, 2012)
Bibliographic References Disadvantages (-)	(Additively, 2017c; Redwood et al., 2017; Varotsis, 2017)	(Additively, 2017b; Hiemenz, 2007; Redwood, 2017)	(Bikas et al., 2016; Huang et al., 2013a; Mahamood et al., 2014)	(Chen et al., 2016; Mahamood et al., 2014; Redwood et al., 2017)	(Mahamood et al., 2014; Redwood et al., 2017; Wong & Hernandez, 2012)	(Additively, 2017a; Gokuldoss et al., 2017; Malladi, 2017; Redwood et al., 2017)	(Additively, 2017d; Gokuldoss et al., 2017; Redwood, 2017; Yasa & Kruth, 2011)	(Bikas et al., 2016; Calignano et al., 2017; Mahamood et al., 2014)	(Gross et al., 2014; Mahamood et al., 2014; Palermo, 2013; Park et al., 2000; Pilipovic et al., 2011; Wong & Hernandez, 2012)

Source: Prepared by authors (2020).

2.2 Additive manufacturing and competitive criteria

Competitive criterion can be conceptualized as what a manufacturer wants to emphasize in terms of future improvements to achieve or maintain their competitive advantage, since they are the factors evaluated by customers at the time of the purchase decision (Thürer et al., 2014). The competitive criteria found in the literature are cost, quality, reliability, speed, delivery reliability, innovation, socio-environmental responsibility and flexibility (Bott, 2014; Dias & Fensterseifer, 2005; Lira et al., 2015; Slack, 2002; Teixeira et al., 2014; Thürer et al., 2014; Wheelwright, 1984).

The criteria are related to the definition of the organization's strategy, that is, the strategy in operations will define in which of these or other criteria it intends to rival (Lee, 2012; Skinner, 1969). In summary, they can be defined as a consistent set of criteria that the company has to value to compete in the market (Miltenburg, 2008).

Regarding the cost criterion, the adoption of Additive Manufacturing is still impacted by this factor. However, from 2001 to 2011, the average price of equipment reduced 51% (Thomas & Gilbert, 2014). Yet in many ways, the costs of using additive processes are still higher when compared to traditional manufacturing (Lindemann et al., 2013; Thomas & Gilbert, 2014). Despite this, the use of AM has been increasing and one of the reasons is that organizations are getting return on investment (Sculpteo, 2017).

As for the competitive flexibility criterion, several authors emphasize this characteristic of Additive Manufacturing as one of the advantages in relation to the traditional manufacturing process (Mahamood et al., 2014; Rüßmann et al., 2015; Tran et al., 2017; Zhai et al., 2014). The impacts of AM technologies possibilities will cause large plant complexes and supply chains to become smaller (Ben-Ner & Siemsen, 2017). Therefore, there will be reflexes in several companies simultaneously, given the high set of variables and relationships involved in supply chain management (Teixeira & Lacerda, 2010).

As for the competitive speed criterion, the implementation of AM technologies will change the future of organizations, such as aspects of production, supply chain, maintenance, product development and the global economy (Ben-Ner & Siemsen, 2017; Ernst & Young GmbH, 2016). Partly, caused by the ability of AM technologies to produce on-demand and profitable parts (Berman, 2012; Ford, 2014). For delivery performance, there needs to be speed and delivery reliability (Li, 2000; Wheelwright, 1984). Some of the benefits of adopting AM technologies are process agility, inventory reduction and reduced transportation costs (Ford & Despeisse, 2016; Rylands et al., 2016; Thomas, 2016). These improvements increase the delivery performance of organizations.

In their work, Kietzmann et al. (2015) highlight AM's potential in reducing delivery time for manufactured products. Likewise, they also present the proposal that consumers will be able to manufacture their own products at home, without the need for intermediaries. These facts indicate that speed is one of the competitive criteria that can benefit companies that adopt this technology (Veit, 2018).

Finally, referring to the quality competitive criterion, it can be conceptualized as the ability of a component to successfully execute its objective, besides being considered important to achieve a competitive advantage (Kuei & Madu, 2003; Wing et al., 2015). Manufacturing and end users have difficulties to guarantee that quality, strength and reliability are ensured when components are produced via Additive Manufacturing (Wing et al., 2015). AM technologies have difficulties to compete with traditional techniques regarding reliability and reproducibility (Royal Academy of Engineering, 2013). Mahamood et al. (2014) affirm that the points not yet solved by AM technologies are precision, surface finish, productivity, repeatability and reliability. As an alternative, to ensure a level of reproducibility, a set of patterns/specifications and hybrid processing are suggested, where AM technology is used in conjunction with conventional techniques (Royal Academy of Engineering, 2013).

Meanwhile, the society seems to be largely unaware of the implications of AM technologies that universities and organizations are researching/developing (Ben-Ner & Siemsen, 2017). Finally, Table 3 displays the repercussions of Additive Manufacturing on competitive criteria according to literature review and content analysis performed by Veit (2018).

Table 3. Impact of Additive Manufacturing on Competitive Criteria.

			Analysis Categories Competitive Criteria						
			Cost	**Delivery Performance**	**Velocity**	**Flexibility**	**Quality**	**Sustainability**	**Innovation**
Impact of Additive Manufacturing on Competitive Criteria	**Positive Repercussions**	Reduced costs for customized products	x						x
		Elimination of the need for tools	x		x				
		Manufacture from drawing	x						x
		Reduced waste of materials	x					x	
		Reduced energy consumption	x					x	
		Reduced transport needs	x	x	x			x	
		More agile supply chains		x	x				
		Reducing the complexity of supply chain management		x					
		Reduction of delivery times		x	x				
		Reduced throughput time for low volumes of high variety		x					
		Reduced time to market		x	x				
		Setup elimination			x	x			
		Allows the use of different types of materials				x			
		Ensures physical and mechanical properties					x		
		Mitigates the environmental impact						x	
		Cleaner production process						x	
		Reduced carbon emissions						x	
		Innovation as a manufacturing process							x
		Facilitates project sharing and outsourcing							x
	Negative Repercussions	High cost of equipment	x						
		Reduced process yield	x		x				
		High cost for series production	x		x				
		Increased cost of intellectual property and information security	x						
		Increases the cost of qualifying labor	x						
		Lacks precision and robustness					x		
		Does not guarantee physical and mechanical properties					x		
		Finishing problems (visible component aspect)					x		

Source: Veit (2018).

In the next section it will be presented the selection of technologies for additive manufacturing.

2.3 Selection of technologies for additive manufacturing

Organizations are inserted in environments of constant change and increasing competition, therefore technology is becoming a key reference to ensuring the competitiveness of companies (Chuang et al., 2009; National Research Council, 1995; Nunes et al., 2015). Nevertheless, high and new technology projects are characterized as high risk and return, in parallel, conflicting objectives complicate the evaluation and selection process (Chuang et al., 2009; Kuei et al., 1994; Mohagheghi et al., 2017; Wang & Chin, 2009).

Managing development decisions based on technologies is a complex task (S.R. & K., 2011). The selection of new technologies is one of the most important activities of many companies (Mohagheghi et al., 2017). Organizations of all sizes, face an increasingly complex scenario regarding the choice of technologies (McKnight, 2016). The most important part of the choice is the construction of an arrangement, where the stakeholders agree and support the final decision (Bocklund et al., 2011). It is considered that the development of a well-executed technology is a product to meet the needs of the customers (National Research Council, 1995).

Technology selection tools seek to reduce existing tradeoffs in the process, apart of simplify key point identification for complex systems (Chan et al., 2006). Inadequate selection in relation to the strategic goals of organizations may result in future reinvestment costs for the company (Bustamente et al., 2010).

During the process of selecting a technology, organizations should explore competitive and operational strategies in the meantime (Chuang et al., 2009). Though, throughout the decision-making process, given the complexity of existing situations/problems, companies choose to carry out a monetary analysis to the detriment of the strategic benefits associated with the technology in question (Borenstein & Betencourt, 2005). Where the development of technology occurs independently, not towards the needs of the stakeholders, the rate of deployment/acceptance of technology is low (National Research Council, 1995).

Regarding existing research, the work of Rao & Padmanabhan (2007) presents a methodology for the selection of Additive Manufacturing technologies using a matrix approach and graph theory. In which, a selection index for technologies is proposed to evaluate and classify processes to manufacture a particular product or parts.

Due to the growth of Additive Manufacturing, Mellor et al. (2014), have developed a framework to assist in the adoption of Additive Manufacturing technologies and thus contribute to supply the lack of studies on implementation.

Mançanares et al. (2015) developed a method to select a more appropriate additive technology considering the production of a specific part. For this, they developed a selection process through the technical specifications of the considered part.

Khaleeq uz Zaman et al. (2016), within the universe of Additive Manufacturing (various materials, technologies, DFM/DFAM techniques), have had a focus on two questions: i) What are the common design criteria used in the literature for Additive and traditional Manufacturing technologies with regard to product process integration? ii) What is the contribution of the literature to the strategies of selection of materials and manufacturing processes with special focus on the comparison of Additive and traditional Manufacturing technologies? That is, this research stands out for proposing a methodology for selecting technologies integrated with product and process development.

Park & Tran (2017) provide a decision support system to select an appropriate 3D printing method for printing end products, using Java and SQL. Based on product requirements, printing methods have been analyzed and evaluated to decide which one meets the product requirements in the best way (Park & Tran, 2017).

Finally, Gokuldoss et al. (2017) conceptually/theoretically address the selection guidelines for the following Additive Manufacturing technologies: *Selective Laser Melting, Electron Beam Melting* e *Binder Jetting*. The attributes considered by the authors are: material type, technology specifications/limitations, characteristics (properties) of parts, application of parts, post processing requirements, finishing quality and accuracy (Gokuldoss et al., 2017).

2.3.1 Comparative analysis of the model of this research with the literature

In relation to the research of Gokuldoss et al. (2017) this work progresses, as it increases from 3 to 9 AM technologies addressed in the model. Additionally, it complements the criteria used (material and component specification, part application, technological limitations, accuracy, finishing quality and post processing) for future research.

Park & Tran (2017), present their research in a partial manner, that is, without demonstrating the steps followed for validation and development of the system. In this way, this research will contribute as a reference for future work to present its system in a functional and total manner, in addition to clearly exposing validation processes, choice of AM technologies and decision-making during the development. It is important that a research presents methodological accuracy so that it is considered solid and relevant, besides enabling its replication.

Regarding the research by Khaleeq uz Zaman et al. (2016) and Mellor et al. (2014), this work will serve as a complement, because, respectively, a research looks after indicate the technology most appropriate to the situation (additive or traditional) and the other refers to the implementation of additive technology.

In relation to the research of Mançanares et al. (2015), this work advances, because, differently, the proposed model can be used in a wide variety of situations, besides enabling, through competitive criteria, the approximation with the strategy of the organization. Finally, in contrast to that developed by Rao & Padmanabhan (2007), this research proposes an automated model. That is, its applicability in organizations is of low level of complexibility and easy execution. In addition, with the increase in the Additive Manufacturing market, this research, for model execution, uses AHP techniques and conjoint analysis. Therefore making the model easy to include new technologies and swift deployment. As follows, this research contributes to reducing the gaps in the literature and the lack of tools to support decision-making, thus facilitating the decision-making process.

3 Methodological procedures

The working method establishes the steps that the researcher will follow to achieve the purposes of the research (Dresch et al., 2015). It is important that the method is concise and structured, so that it allows it to be replicated, adding certainty as to the veracity of theory or research (Mentzer & Flint, 1997). In this research was used to conduct this work the *Design Science Research*. DSR is defined as the "[…] science that seeks to consolidate knowledge about the design and development of solutions to improve existing systems, solve problems and create new artifacts" (Dresch et al., 2015, p.59). The working method used in this research is illustrated in Figure 1.

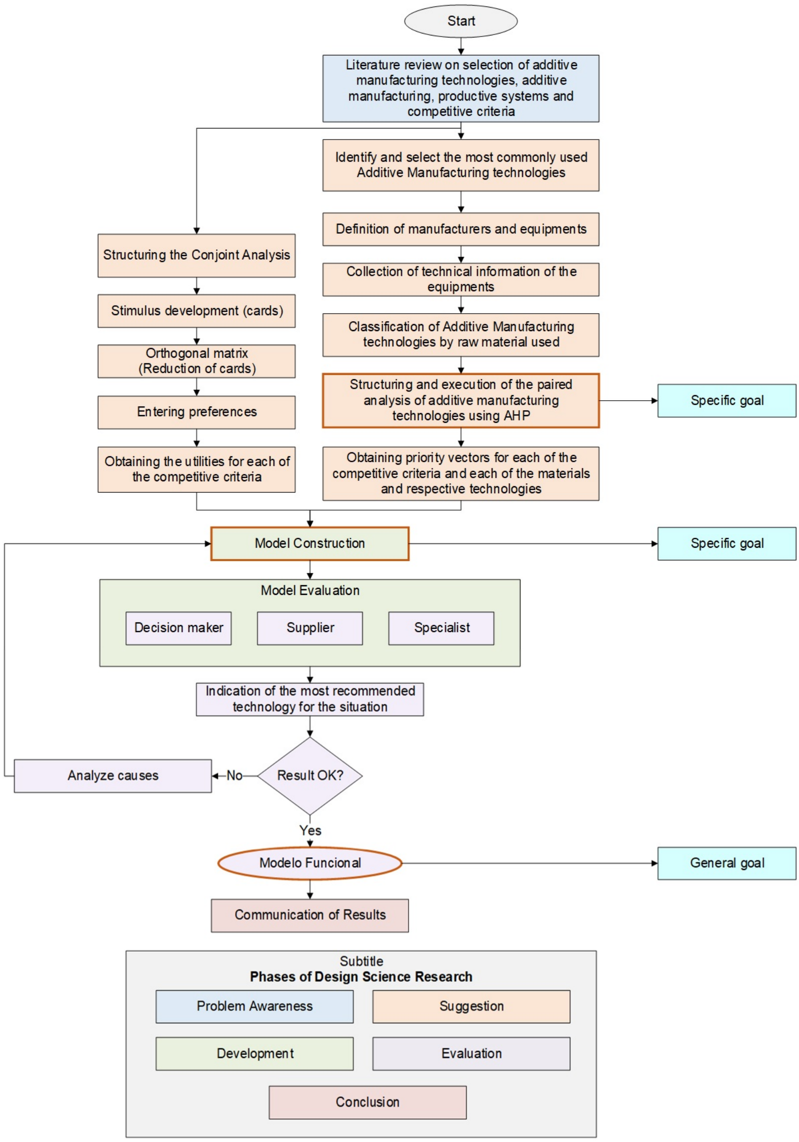

Figure 1. Method Steps (Artifact). Source: The Authors (2020).

The starting point is located in the identification and awareness of the research problem, namely the selection of Additive Manufacturing technologies in production systems. At this stage, an effort is made to understand the problem (Simon, 1996), besides being the stage where the researcher should seek as much information as possible, ensuring the complete understanding of his particular and distinctive characteristics (Dresch et al., 2015). It should be considered the artifact features, expected performance and operating requirements (Dresch et al., 2015). For this, a literature systematic review was carried out using national and international databases. Where research linked to Additive Manufacturing, its technologies and technology selection were sought.

Defined the technologies that will be part of the model, the identification and survey of the characteristics of 3D printers was initiated through the technical documentation of Additive Manufacturing equipment manufacturers. This information was related both to the characteristics evidenced in the literature and with the competitive criteria. These references constituted the artifact database. Information about 3D technologies/printers can be verified in Appendix A1.

Subsequently, AM technologies were classified by contemplated raw material. This detachment was performed in order to make paired analysis of AM technologies leaner and make the model database organized and easy to handle. Furthermore, in addition to ordering by competitive criterion, the classification by raw material caused each paired analysis to contemplate a maximum of four technologies, making the classification process faster, easier and less prone to any filling errors.

Ranked the raw material technologies, paired analysis of additive technologies was performed in relation to each competitive criterion using the Analytic Hierarchy Process technique (AHP). AHP was chosen because it is a technique used to solve complex problems (Piran et al., 2018), being used to perform the paired analysis of technologies in relation to competitive criteria. Being this applied for the resolution of unstructured problems in the area of management, social and economic sciences (Mahalik & Patel, 2010).

To establish resources among the elements during an analysis, the Saaty Scale by Saaty (1990) was used to classify. The Saaty Scale was employed because it was a validated and consolidated scale. Once the comparison is performed, the priority vector from AHP is obtained. Moreover, to evaluate this vector, subsequently, the consistency should be calculated to evaluate the quality of judgments and also to evidence the need for modifications (changing questions of the survey, reordering elements, etc.) until the consistency index is a maximum of 10%, a value indicated by Saaty (1990).

Once the first step of the method is done, the structuring of the conjoint analysis begins. This technique is performed to obtain the usefulness that respondents attribute to the relevant criteria (Malhotra, 2012), in this research, the competitive criteria. Thus obtaining utilities by identifying the preferences of the respondents through the ordering of cards. That is, after performing the conjoint analysis, the optimal combination of characteristics (Hair et al., 2006) can be defined. Stimulus cards were developed to perform conjoint analysis.

With the specific combinations (stimuli), the researcher seeks to understand the preference structure of the respondent (Hair et al., 2006). This research will use the full profile procedure, where complete profiles are built for all attributes (Malhotra, 2012). And for each of the attributes, this research adopted 3 levels, they are “High”, “Medium” and “Low”.

Aiming to make the model leaner, through the reduction of cards, the orthogonal matrix was performed. This matrix presents sufficient combinations to analyze the effects/utilities for each level of profiles/factors (Malhotra, 2012; Montgomery, 2012). With these finalized steps, it was necessary to collect the ordering of stimuli to obtain utilities for each of the competitive criteria. Additionally, given the nature (specific preferences of the interviewees/company in question) that prevent generalizations of the result and the sample size, the external validity cannot be evaluated. After the first and second stage of the method, the model is constructed through the integration of AHP techniques and the conjoint analysis.

The concomitant use of the two techniques was necessary to overcome the limitations. Because of this, both techniques were not fully implemented. AHP performs comparisons only par-par, this way making it impossible to analyze all competitive criteria at the same time. This limitation would cause the interviewee's analysis to be complex and time-consuming, besides, impacting the respondent's consistency during execution. However, for the preparation of the database, the AHP technique was used. In that, it allows in a simple way, the paired analysis of all competitive criteria in relation to each of the raw materials and AM technologies. As for the conjoint analysis, this enables the analysis of all competitive criteria at the same time, however, the final result of the technique, is the general usefulness. For this research, the “intermediate” utility was used, i.e., of each of the competitive criteria. As well, using conjoint analysis to implement the analysis of all competitive criteria in relation to each of the raw materials and AM technologies would be complex and time-consuming. For that, it would take a high number of stimuli to match all technologies and competitive criteria, thus making the process unfeasible.

The integration was made by multiplying the priority vector by utility, thus obtaining the resulting value. Once this has been done, the AM technology is indicated for the situation in question. The model considers the characteristics of additive technologies and competitive criteria, so that the indicated technology is aligned not only with productive needs, but also with the organization's strategy. After indication, the evaluation of the result is performed. If there are differences in relation to that acquired by the interviewee, the causes are analyzed. If it’s something attributable to the model, it’s reviewed and the process is repeated, if related to the decision-maker, the reasons are evidenced.

Once the development phase is complete, the artifact was applied in real situations, with the decision-maker, suppliers and specialists. Three different types of audiences were selected in order to evaluate the indication of the model from dissimilar perspectives. With an expert in the area, for its impartiality and knowledge to evaluate the result; with a supplier of AM technologies and its commercial bias; finally, with the final decision-maker and the actual situation and its variables.

By this means, the interviewee himself cast an experienced situation in which he participated in the decision-making process, additionally, a questionnaire was applied that can be visualized in Appendix A2. Based on this case, after the execution of the artifact, it was verified whether the indication of the model fits the existing reality at the time of decision making/purchase of the technology. So, the indication was compared with the acquired technology, along to the survey responses and utilities obtained in the conjoint analysis to be analyzed to verify whether they are aligned with the result. Any discrepancies, are treated on the basis of the questionnaire and utilities obtained to identify the cause.

In the end, the results were communicated. At this stage, the conclusions, the results of the research, contributions, aspects of the model improvement, the limitations and suggestions of future work were listed. In which the “Decision Support Model for The Selection of Additive Manufacturing Technologies in Productive Systems” was communicated through the availability of this research in a public access environment. Dresch et al. (2015) advocate the importance that the knowledge generated can be generalized to other situations/problems, thus allowing the advancement of general knowledge.

To add certainty as to the veracity of theory or work, it is necessary that it is replicated, as such a way, the method must be concise and structured (Mentzer & Flint, 1997). From this perspective, the stages of data collection and analysis are presented.

3.1 Systematic review of the literature

The terms "Additive Manufacturing Technologies" and "Selection of Additive Manufacturing Technologies" were researched in national and international databases. No temporal clipping was used, given the objective of verifying the publications that relate to the research issue, but also the search for a widely understanding of the theme.

So, 1,874 results were obtained, where, after an analysis of the titles, 350 articles were selected and categorized by theme and/or technology and/or subject addressed. After categorization, it was necessary to create the following exclusion criteria:

- Articles of development of new materials that did not present characteristics about the Additive Manufacturing machines in question;
- Experiments, studies or research with general information that does not add knowledge to the theme of this research.

A total of 136 articles were selected. These will be used in the construction of section 2 - Theoretical Framework. Of these, 6 articles related to the theme of this research. To select these six studies, only the works that effectively proposed some method, model, framework and/or tool for selecting AM technologies were considered. It is perceived that these 6 articles represent only 2% of the total selected.

Figure 2 illustrates the time horizon in the academic environment of the term "Additive Manufacturing". The surveys were divided into two time clippings to highlight the increase in the number of surveys in the last three years.

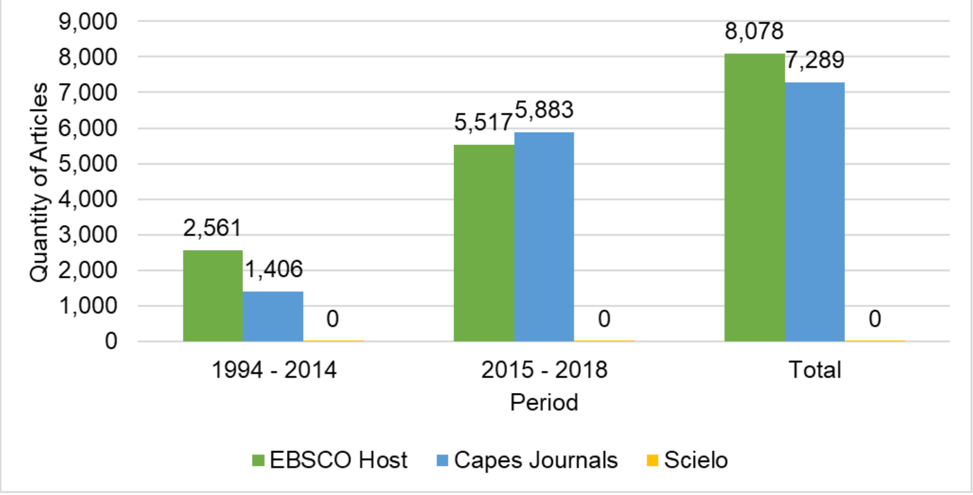

Figure 2. Time Horizon of the term "Additive Manufacturing" Source: Veit (2018).

The results suggest that AM technologies have received greater attention from the scientific community since 2015. For when compared to this three-year period with the last twenty years of research, it is noticed that there has been an increase of almost

300%. However, although the research increased significantly, the problems described in the previous section, including the lack of comparability tools, gap in the literature, among others, remain.

Besides, of the 6 research on the selection of AM technologies, four have occurred in the last 4 years. Suggesting that this topic has not received attention from part of the academy, however, it indicates that this subject begins to be debated by the academic community, still in an unsatisfactory way. This research can contribute to reducing the lack of tools to support decision making regarding the selection of Additive Manufacturing technologies in production systems. Furthermore, studies show that approximately 80 to 90% of companies do not yet have experience or are experimenting/testing AM technologies (Ernst & Young GmbH, 2016; Sculpteo, 2017). This way, it is highlighted the increasing importance of selecting AM technologies.

Research on AM was found in several segments, such as the area of health sciences (Brunello et al., 2016; Fatemi et al., 2017; Pucci et al., 2017; Yao et al., 2016; Schelly et al., 2015; Tsai & Wu, 2014), engineer (Ding et al., 2015; Holmes & Riddick, 2014; Kara, 2013; Li et al., 2017; Vartanian & McDonald, 2016; Yasa & Kruth, 2011), biological science (Delgado et al., 2010; Mazzoli, 2013; Poh et al., 2016; Zadpoor, 2017), among others. These studies corroborate the fact that AM is and will be used in the most diverse applications (Ernst & Young GmbH, 2016; Grynol, 2012; Sculpteo, 2017; Zhai et al., 2014).

There are difficulties and lack of studies on the selection of Additive Manufacturing technologies (Gokuldoss et al., 2017; Park & Tran, 2017; Rao & Padmanabhan, 2007). The results found show that there are limitations regarding the selection of AM technologies, thus having room for new propositions. Meaning, in fact, this research will help to reduce existing gaps, at least partially. These gaps refer to the parameters considered for evaluation, the inclusion of competitive criteria and consequent translation of the organization's strategy, process automation, productive system objectives and decision-making support.

3.2 Data collection and analysis

In this section, data collection and analysis is explained. The collection was carried out in three stages, the first supports the awareness of the problem through the literature review, the second refers to obtaining technical information for the artifact database and, finally, the third that refers to the execution of the conjoint analysis.

The first data collection was the systematic review of the literature performed according to Appendix A2. This review aimed to relate the object of research with the literature within the scope of production systems, selection of technologies, competitive criteria and Additive Manufacturing and its technologies. The research supported the awareness of the problem (Step 1 of the Working Method).

Subsequently, the second data collection was carried out that refers to the technical information of AM technologies. From the technical catalogs of the printers of AM technologies, considered in this research, the technical information was collected for the elaboration of the computational tool database. Because it is a documentation made available by the respective manufacturers, it was not necessary to validate the information. For the selection of manufacturers that make up the database, all listed in the publication of the 3D Hubs (2016) was used. This publication was used as a selection criterion, because 3D Hubs is the world's largest network of manufacturing services, being a platform that offers 3D printing, CNC machining and injection molding through a network of more than 7,000 partners. According to 3D Hubs (2016), these manufacturers are the most popular with AM technology equipment. Regarding the 9 selected AM technologies, these besides being the most prominent in the literature review, are the most commonly used in the industry (Redwood, 2017).

For the preparation of the database, the main technical characteristics of the catalogs of all manufacturers were collected and subsequently related to the characteristics evidenced in the literature (Table 2). In which, it was found that the item "Surface Quality" was not included in the manufacturers' catalogues. The database for manufacturers' information on printers can be verified in Appendix A1. For each of the identified items, the following criteria were used:

- Speed: considered the highest speed found among the manufacturers of each of the AM technologies;
- Maximum prototype size: currently, industrial machines practically do not have this barrier. Because of this, in the technologies in which it was possible, an average and similar size was selected between them;
- Accuracy: considered the highest precision found among the manufacturers of each of the AM technologies;
- Layer thickness: Considered the lowest layer thickness found among the manufacturers of each of the AM technologies;
- Price: Considered the average value found on the manufacturers' website or on the Aniwaa website. Aniwaa is an information platform on Additive Manufacturing technologies;
- Surface quality: if it is flagged as an advantage ("+") by the literature, adding "+1" to the note assigned to perform the paired analysis of technologies;
- Material (Appendix A3): all raw materials indicated by manufacturers for each of the Additive Technologies were considered.

After the computational tool project, the third data collection was performed. In which the computational tool was applied in order to verify the usefulness of the model. This data collection was performed in three moments.

The first step refers to a questionnaire composed of open questions. Open questions were used, as they are used for more in-depth and more accurate research (Dresch et al., 2015). This questionnaire has two objectives: i) assist in the analysis of the results, where the result of the conjoint analysis and the artifact will be related to information from the interviews in order to support the recommendation and/or solve any divergences; and ii) make the interviewee remember the situation at the time of the decision-making process regarding the acquisition of additive technology. The questionnaire is presented in Appendix A2. Additionally, the interviews were analyzed comparing the answers with the utilities obtained through the ordering of the cards.

The second stage deals with the presentation of the chart of definitions of the competitive criteria and its relationship with certain characteristics of additive manufacturing technology equipment contained in Table 4 for the interviewees. This chart was presented before the start of issues related to competitive criteria. Where, the interviewees made the reading to understand the concepts and eventually answer doubts. In addition, the definition scan ensured the correct understanding/definition of the concepts used in this research, besides ensuring that all interviewees have the same understanding.

Table 4. Definitions and relation of competitive criteria with certain characteristics of Additive Technologies.

Competitive Criteria	Definition	Characteristic of Additive Technology	Relationship
Cost	Cost for acquisition.	Acquisition value	The smaller the better
Flexibility	The company's ability to adapt its products to customer needs or to an individual customer.	Maximum size of prototypes Layer thickness	The bigger the better The smaller the better
Quality	Offer products that are produced according to pre-established standards and low defect rate.	Precision Surface Quality	The bigger the better The bigger the better
Velocity	The company's ability to deliver products in the shortest possible time.	Velocity	The bigger the better

Source: The Authors (2020) based in (Ernst & Young GmbH, 2016; Mahamood et al., 2014; Tran et al., 2017; Wheelwright, 1984).

Finally, in the third stage, the cards, called stimuli, are used, which are necessary for the execution of the conjoint analysis. With the specific combinations of stimuli, the researcher seeks to understand the preference structure of the respondent (Hair et al., 2006). The cards are organized by the participants in order of preference, according to the competitive criterion (and their relation with a certain characteristic of AM technology equipment) that most represent the desired attributes in the production system at the time of the process of decision/acquisition of the technology in question. The cards used in this search can be viewed in Appendix A4.

With regard to the sample, there are no restrictions on the demographic region, only that the company is located in Brazil, regardless of whether it is a parent or subsidiary. So, this research will work with companies that, along with working in Brazil, are investing in AM technologies in Brazil.

As for the delimitations, three are presented: only positions related to production systems are accepted, the company in question has AM technology equipment implemented and, finally, that the interviewee participated in the decision-making process/purchase of additive technology. These criteria are fundamental to allow the correct validation or not of the model. The reasons for these delimitations are: regarding the position, due to the focus of this research being the productive systems; related to having the equipment, so it is possible to verify the effectiveness or not of the model and also by the experiences acquired in the decision-making process; finally, having participated in the decision-making process, purpose is to have participants who are aware of the technology acquired, besides having passed through the process as a whole (information difficulties, learning, etc.).

This work will use convenience sampling, in which according to Hair et al. (2005) and Malhotra (2012) a sample of elements is obtained based on the convenience of the researcher, that is, according to availability, besides being a low cost and quick way to obtain the results. This method is also used in the exploratory phase, where the goal is to develop a hypothesis or get a better view on a problem in question (Hair et al., 2005; Malhotra, 2012).

However, the reasons for this research have used convenience sampling, it is not only issues of availability and/or ease, but for questions presented in advance. Such as: the existence of few companies that use AM technologies, the fact that Additive Manufacturing is not widely disseminated in Brazil, the deficiency of information both in the academic and business environment and the need for respondents who have participated in the decision-making process.

As for the reasons for choosing the Supplier, in addition to the communication channel, existing between the Supplier and the University due to participation / support in other research, the company in question operates in the area of Additive Manufacturing Technologies for 30 years and is currently recognized as a world leader in 3D printing, that is, consolidated company and relevance for participation in this research. In addition, it has offices in Brazil, Mexico, Chile, the United States, Germany, Israel, Japan, South Korea, India and Australia, totaling approximately 2,500 employees. Working in the automotive, products, medical, dental and aerospace segments in FDM, SLA, EBM, SLS and MJ technologies.

Regarding the Specialist, in addition to the communication channel between the Supplier and the University due to participation/support in other research, with respect to qualification, he is a mechanical technician by the Jacareí Institute of Technology, graduated in Mechanical Industrial Engineering from the Portão State Technical School (ETEP) and holds a Master's degree in Aeronautical and Mechanical Engineering from the Technological Institute of Aeronautics - ITA. Besides that, he has experience in the area of conventional and unconventional manufacturing processes: machining, vibration control in *high speed cutting* and Additive Manufacturing. Works professionally in the area of Integrated Solutions in Metalmechanics, works in innovation projects related to the manufacturing area and AM technologies. That is, the Specialist works in the area of AM technology, as well as indicating the AM technologies for the situation presented, in addition to its academic/professional performance being aligned with the general objective of this research.

4 Proposition and model development

For the development of the artifact, two techniques were used in a combined Analytic Hierarchy Process (AHP) and conjoint analysis. The partial use of the two techniques was necessary to overcome the limitations, the HPA due to the execution of comparisons par-par and the conjoint analysis by complexity to analyze all criteria. The Figure 3 presents the statistical structuring of the model.

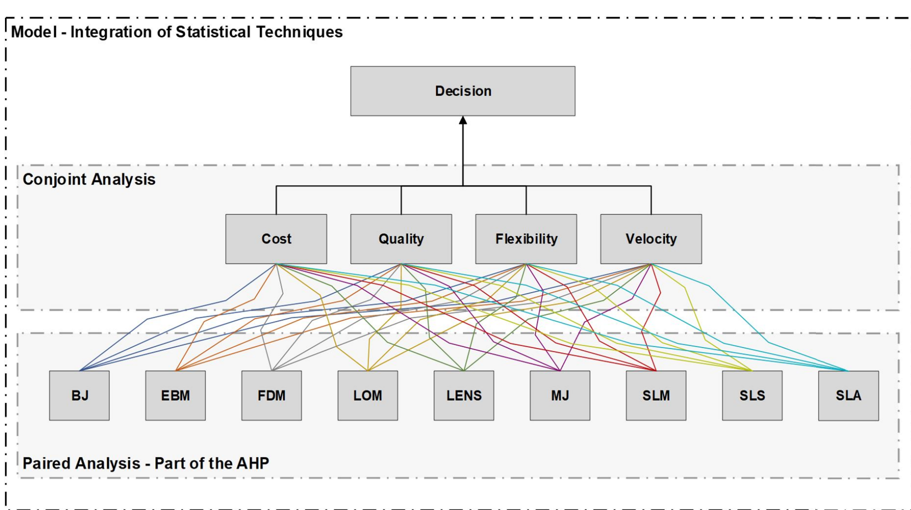

Figure 3. Structuring statistical techniques in the Model. Source: The Authors (2020).

The construction of the model is divided into two stages, they are the execution of the AHP technique and the Conjoint Analysis. For the application of AHP, the next steps were followed: (Piran et al., 2018; Saaty, 1983, 1990; Thanki et al., 2016):

1. Construction of the hierarchy of the decision;
2. Comparison among hierarchy elements;
3. Analysis of the relative priority of each criterion;
4. Assess the consequences of relative priorities;
5. Construction of the parity-check matrix for each criterion, considering each of the selected alternatives;
6. Obtaining the compound priority for the alternatives;
7. Choice of the alternative.

Steps 1, 2, 3, and 4 were not performed, as these are related to the process of choosing the AHP technique. And for this process, this research used Conjoint Cnalysis (next section), this article will present the integration of AHP with Conjoint Analysis.

For each of the competitive criteria, a relation was established between the competitive criterion and the printer feature, validated by a specialist. As presented in the data collection section, this specialist was chosen, among other reasons, because he has qualification in the area and for acting professionally in the implementation of Additive Manufacturing technologies, in addition to conduct/having conducted academic research in the area of AM. This relation can be viewed in Table 5.

Table 5. Relation between competitive criteria and additive technology characteristics.

Competitive Criteria	Characteristic of Additive Technology	Relationship
Cost	Acquisition value	The smaller the better
Flexibility	Maximum size of prototypes Layer thickness	The bigger the better The smaller the better
Quality	Precision Surface Quality	The bigger the better The bigger the better
Velocity	Velocity	The bigger the better

Source: The Authors (2020).

Subsequently, the values of each database technology were distributed in a normalized manner in the Saaty Scale. For this, the first stage was the normalization of the data, where the difference between the highest and lowest value was made and the result divided by 9 (maximum number of the Saaty Scale). With the result, the second stage began, from the minimum value selected, among the AM technologies, for each competitive criterion, the result of normalization was added to the distribution between the 9 numbers of the scale. The Table 6 displays the scale used for each of the competitive criteria considering the characteristics of each technology.

Table 6. Classification Scale.

	Competitive Criteria	Quality	Cost	Flexibility		Velocity
	Characteristic of Additive Technology	Precision	Cost	Maximum size Prototype	Layer Thickness	Velocity
Saaty scale	1	170 µm or more	$ 220,000.00 or more	0.009 m^3	337 µm or more	0.00059 mm/h
	2	155 µm	$ 205,000.00	0.01263066 m^3	297 µm	0.0024 mm/h
	3	140 µm	$ 190,000.00	0.0361 m^3	257 µm	14 mm/h
	4	125 µm	$ 175,000.00	0.03822 m^3	217 µm	16.65 mm/h
	5	110 µm	$ 160,000.00	0.05851678 m^3	177 µm	32 mm/h
	6	95 µm	$ 145,000.00	0.06936 m^3	137 µm	76.2 mm/h
	7	80 µm	$ 130,000.00	0.07056 m^3	97 µm	1828800 mm/h
	8	65 µm	$ 115,000.00	0.4655 m^3	57 µm	28800000000 mm/h
	9	50 µm	$ 100,000.00	1.22 m^3 or more	17 µm	34800000000 mm/h

Source: The Authors (2020).

With the defined scale, the material matrix was elaborated. This matrix aims to group technologies by worked material. For, there is no need to perform the paired analysis of all AM technologies together, due to the fact that each AM technology works with certain materials. Figure 4 displays the matrix of raw materials. As the matrix output is the Comparison Matrices and the Normalized and Priority Vector Matrices, both obtained using the AHP Technique and the Saaty Scale, as explained earlier.

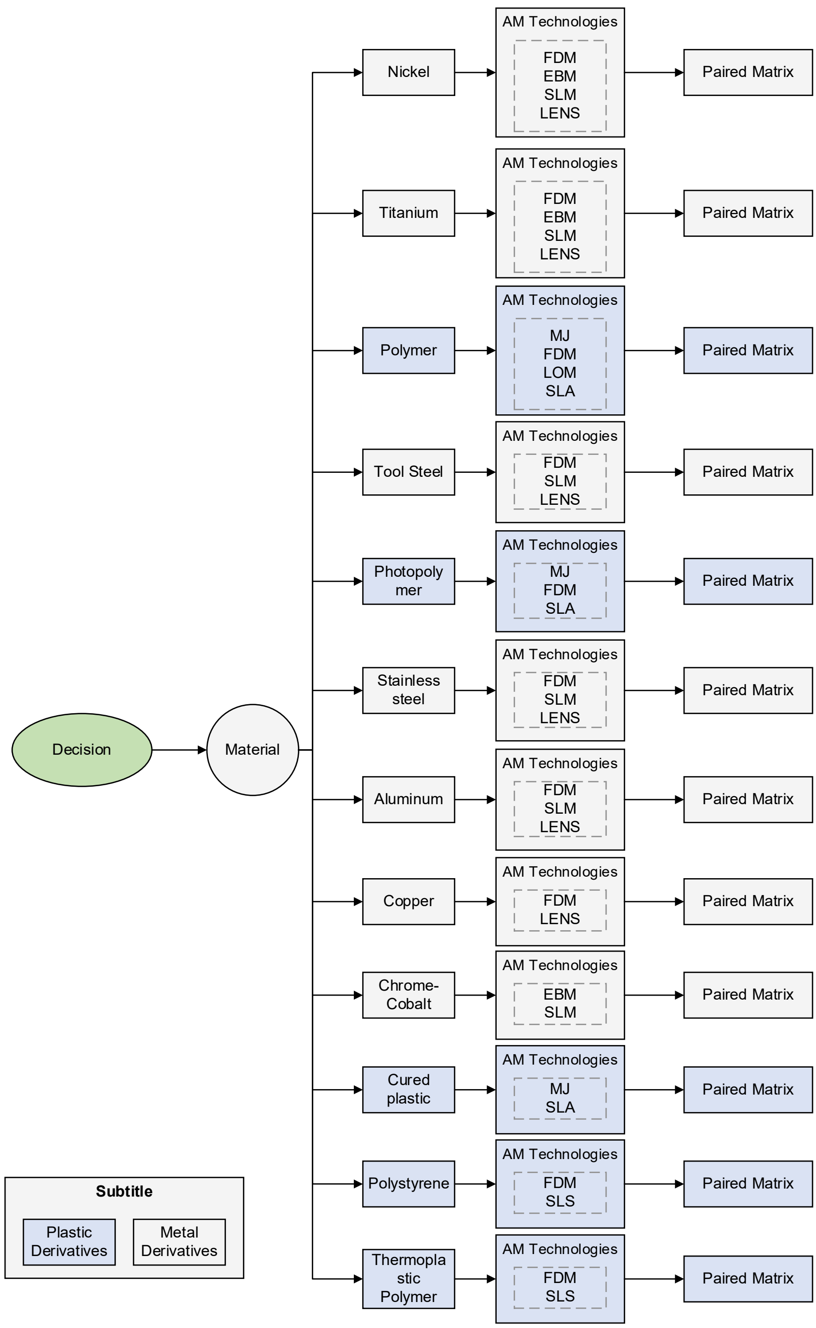

Figure 4. Additive Manufacturing Technology Classification Matrix according to The Raw Materials Worked. Source: The Authors (2020).

The other raw materials contemplated in this research are not listed. This is due to the fact that they are used by a single technology, thus dispensing the usage of this model. It can be affirmed that in this case, of exclusive raw material of a single technology, it is a qualifying criterion – because AM technology is chosen instantly.

According to the raw materials contemplated, the technologies are classified, and the comparison matrix is carried out. This array is important for establishing priorities between the elements of each hierarchy level (Piran et al., 2018). For each material, the comparison matrix was executed amongst the technologies that use a particular material. After that, the normalization of the data was performed. The normalization of priority matrix data is obtained by dividing the value of each component by summing all column values (Piran et al., 2018). Subsequently, the priority vector is performed, obtained through the average of the normalized values of each competitive criterion (Piran et al., 2018). Table 7 displays the priority vector for each of the raw materials and their AM technologies. The materials not listed work with only one of the nine technologies used in this research – thus dispensing with paired analysis.

Table 7. Comparison Matrix - Material x Technology.

MATERIALS	TECHNOLOGY	VECTOR PRIORITY - STANDARD MATRIX			
		COST	FLEXIBILITY	QUALITY	VELOCITY
Nickel Alloy	Fused Deposition Modeling (FDM)	0.400000000	0.083369266	0.732759740	0.053023855
Nickel Alloy	Electron Beam Melting (EBM)	0.200000000	0.845650187	0.119274892	0.575166243
Nickel Alloy	Selective Laser Melting (SLM)	0.200000000	0.507186273	0.087911255	0.081685498
Nickel Alloy	Laser Engineering Net Shape (LENS)	0.200000000	0.563794274	0.060054113	0.290124405
Titanium Alloy	Fused Deposition Modeling (FDM)	0.400000000	0.083369266	0.732759740	0.053023855
Titanium Alloy	Electron Beam Melting (EBM)	0.200000000	0.845650187	0.119274892	0.575166243
Titanium Alloy	Selective Laser Melting (SLM)	0.200000000	0.507186273	0.087911255	0.081685498
Titanium Alloy	Laser Engineering Net Shape (LENS)	0.200000000	0.563794274	0.060054113	0.290124405
Polymer	Material Jetting (MJ)	0.072587421	1.027140468	0.042118529	0.750000000
Polymer	Fused Deposition Modeling (FDM)	0.106300272	0.549152731	0.581769465	0.083333333
Polymer	Laminated Object Manufacturing (LOM)	0.736620124	0.179303233	0.188056003	0.083333333
Polymer	Stereolithography (SLA)	0.084492183	0.244403567	0.188056003	0.083333333
Tool Steel	Fused Deposition Modeling (FDM)	0.500000000	0.128086755	0.808441558	0.103328469
Tool Steel	Selective Laser Melting (SLM)	0.250000000	0.926855317	0.117604618	0.174136613
Tool Steel	Laser Engineering Net Shape (LENS)	0.250000000	0.945057928	0.073953824	0.722534918
Photopolymer	Material Jetting (MJ)	0.261111111	0.916371863	0.064018219	0.818181818
Photopolymer	Fused Deposition Modeling (FDM)	0.411111111	0.658782394	0.499240891	0.090909091
Photopolymer	Stereolithography (SLA)	0.327777778	0.424845742	0.436740891	0.090909091
Alloy Stainless Steel	Fused Deposition Modeling (FDM)	0.500000000	0.128086755	0.808441558	0.103328469
Alloy Stainless Steel	Selective Laser Melting (SLM)	0.250000000	0.926855317	0.117604618	0.174136613
Alloy Stainless Steel	Laser Engineering Net Shape (LENS)	0.250000000	0.945057928	0.073953824	0.722534918
Aluminum Alloy	Fused Deposition Modeling (FDM)	0.500000000	0.128086755	0.808441558	0.103328469
Aluminum Alloy	Selective Laser Melting (SLM)	0.250000000	0.926855317	0.117604618	0.174136613
Aluminum Alloy	Laser Engineering Net Shape (LENS)	0.250000000	0.945057928	0.073953824	0.722534918
Copper Alloy	Fused Deposition Modeling (FDM)	0.666666667	0.242857143	0.900000000	0.142857143
Copper Alloy	Laser Engineering Net Shape (LENS)	0.333333333	1.757142857	0.100000000	0.857142857
Chrome-Cobalt Alloy	Electron Beam Melting (EBM)	0.500000000	1.333333333	0.666666667	0.875000000

Table 7. Continued…

MATERIALS	TECHNOLOGY	VECTOR PRIORITY - STANDARD MATRIX			
		COST	FLEXIBILITY	QUALITY	VELOCITY
Chrome-Cobalt Alloy	Selective Laser Melting (SLM)	0.500000000	0.666666667	0.333333333	0.125000000
UV Cured Plastic / Heat Resistant / Gray	Material Jetting (MJ)	0.500000000	1.100000000	0.142857143	0.900000000
UV Cured Plastic / Heat Resistant / Gray	Stereolithography (SLA)	0.500000000	0.900000000	0.857142857	0.100000000
Polystyrene	Fused Deposition Modeling (FDM)	0.666666667	0.642857143	0.900000000	0.166666667
Polystyrene	Selective Laser Sintering (SLS)	0.333333333	1.357142857	0.100000000	0.833333333
Thermoplastic Polymer	Fused Deposition Modeling (FDM)	0.666666667	0.642857143	0.900000000	0.166666667
Thermoplastic Polymer	Selective Laser Sintering (SLS)	0.333333333	1.357142857	0.100000000	0.833333333
Acrylic (Similar)	Material Jetting (MJ)	-	-	-	-
Synthetic Ceramic Sand	Binder Jetting (BJ)	-	-	-	-
Rubber	Material Jetting (MJ)	-	-	-	-
Cellulose	Laminated Object Manufacturing (LOM)	-	-	-	-
Fiberglass	Fused Deposition Modeling (FDM)	-	-	-	-
PET filament with Propylene glycol	Fused Deposition Modeling (FDM)	-	-	-	-
Polymer filament with wood fibers	Fused Deposition Modeling (FDM)	-	-	-	-
Polymer filament with copper particles	Fused Deposition Modeling (FDM)	-	-	-	-
Polymer filament with Bronze powder	Fused Deposition Modeling (FDM)	-	-	-	-
Cobalt Alloy	Laser Engineering Net Shape (LENS)	-	-	-	-
Refractory Alloy	Laser Engineering Net Shape (LENS)	-	-	-	-
Cast Metal	Stereolithography (SLA)	-	-	-	-
Nylon filled with Aluminum powder	Selective Laser Sintering (SLS)	-	-	-	-
Iron and Chromium Oxide	Binder Jetting (BJ)	-	-	-	-
Polyamide	Selective Laser Sintering (SLS)	-	-	-	-
Polyamide with carbon fibers	Selective Laser Sintering (SLS)	-	-	-	-
Polycarbonate	Stereolithography (SLA)	-	-	-	-

Source: Search Data (2019).

The criterion with higher priority vector has a greater impact on the central objective of the analysis (Piran et al., 2018). Finally, for each of the priorities, it is necessary to carry out the assessment of the consistency of the relative priorities. The ratio of consistency should be 10% or less to be acceptable, if not, the quality of the analyses should be improved (Saaty, 1983). All results were acceptable as set out in Table 8, raw materials with two or fewer technologies is not calculated consistency and finally, the other raw materials are used by a single Additive Manufacturing technology.

Table 8. Obtained Consistencies.

		Raw Material											
		Nickel	Titanium	Polymer	Steel Tool	Photopolymer	Stainless Steel	Aluminum Alloy	Copper Alloy	Chrome-Cobalt Allot	Plastic Cured	Polystyrene	Thermoplastic Polymer
Competitive Criteria	**Cost**	0.00%	0.00%	2.40%	0.00%	4.79%	0.00%	0.00%	-	-	-	-	-
	Flexibility - Prototype Size	1.50%	1.50%	1.40%	2.67%	2.81%	2.67%	2.67%	-	-	-	-	-
	Quality	8.00%	8.00%	0.07%	9.52%	0.02%	9.52%	9.52%	-	-	-	-	-
	Velocity	7.11%	7.11%	0.00%	4.25%	0.00%	4.25%	4.25%	-	-	-	-	-
	Flexibility - Layer Thickness	4.10%	4.10%	0.00%	3.86%	0.00%	3.86%	3.85%	-	-	-	-	-

Source: Search Data (2019).

After the AHP technique, the development of the conjoint analysis begins.. This is used to evaluate consumer judgments on product and service attributes (Green & Wind, 1975). Stimuli are used for the execution of the conjoint analysis, in this research, cards were used. With the specific combinations (stimuli), the researcher seeks to understand the preference structure of the respondent (Hair et al., 2006). Profiles were made considering all the possibilities/variations. And also, for each of the attributes, this research adopted 3 levels, they are “High”, “Medium” and “Low”.

As there are three levels for each of the four factors (competitive criteria), so there are 64 combinations (4^3). In order to make the model lean, the fractional factorial method was used to reduce the amount of combinations to a smaller number; the result is called orthogonal matrix. This matrix presents sufficient combinations to analyze the effects/utilities for each level of profiles/factors (Malhotra, 2012; Montgomery, 2012). This research obtained 9 stimuli that can be visualized in Appendix A4. As examples of works that used fractional method/orthogonal matrix one can mention (Chennakesava Reddy & Shamraj, 1998; Cobb & Clarkson, 1994; Gökkuş et al., 2017; Kc et al., 2016; Kim et al., 2005).

With the amount of stimuli defined, the process of execution of the conjoint analysis begins through data collection. Initially, the interviewee should specify the used material, later, put the cards in order to represent the situation experienced in the productive system in question. Please note that the order should be made from the most preferred situation to the least. With the ordering of the stimuli collected, the development of the conjoint analysis begins.

As for internal validity, it can be evaluated in terms of correlation between the values data versus the estimated values for the dependent variable (Green & Srinivasan, 1978). In this work, the ordering of stimuli (cards) is a non-metric variable, so internal validity should be estimated by the Kandall’s Tau, indicated for ordinal variables (where there is ordering between categories). For confirmation of the reliability and validity of the results Kendall's Tau values for normal cards should be significant ($p < 0.050$).

With the priority vectors obtained through the HPA and the utilities obtained for each of the competitive criteria through the Conjoint Analysis, the model proposal started through the integration of statistical techniques.

The integration of AHP techniques and conjoint analysis is carried out by multiplying the priority vector by the usefulness found for each of the competitive criteria for each of the technologies. Multiplication is done to perform the composition of the functions. Scheme 1 shows the equation of the model proposed in this research and Table 9 shows the calculation.

$$\begin{gathered}\textit{Decision Support Model for Selection of}\\ \textit{Additive Manufacturing Technologies}\\ \textit{in Productive Systems}\end{gathered} = \underbrace{\left[\begin{gathered}(\textit{Total value for product})\ ij \ldots nij\\ = \textit{Partial utility of level } i \textit{ for factor } 1 +\\ \textit{Partial utility of level } j \textit{ for factor } 2 + \cdots +\\ \textit{Partial utility of level } n \textit{ for factor } m\end{gathered}\right]}_{(\textit{Conjoint Analysis})} \times \underbrace{\textit{Priority Vector}}_{(\textit{AHP})}$$

Scheme 1. Decision Support Model for the Selection of Additive Manufacturing Technologies in Productive Systems. Source: The Authors (2020).

Table 9. Calculation Statement - Artifact Indication.

Technology	Priority Vector / Utility				Preferences
	Cost	Quality	Flexibility	Velocity	
Tec. 1	vp1 / u1	vp1 / u1	vp1 / u1	vp1 / u1	1
Tec. 2	Vp2 / u2	vp2 / u2	vp2 / u2	vp2 / u2	2
Tec. "n"	Vp n / u n	Vp n / un	vpn / un	vpn / un	n

Source: The Authors (2020).

Where, the priority vector is multiplied by utility for each of the technologies. That is: (tec1 vector priority cost x tec1 utility cost) + (....) + (vp1 x u1) = preference. The technology with the highest resulting value (preference), refers to additive technology that best suits the situation considered in the execution of the artifact, that is, the output of the model developed in this research.

5 Results

This section presents the results of the artifact. The results will be presented in three different aspects: the first will be relative to the decision-maker's point of view, the second of the supplier and, finally, the specialist.

Regarding the decision-maker, this study worked with 2 respondents who were interviewed. Table 10 shows the profile of both the interviewees and the company in which they work at the time of the acquisition of the equipment.

Table 10. Interviewees' Profile - Decision makers.

Description	Interviewee 1	Interviewee 2
Company operating area	Plastic branch for the civil construction market	Orthopedic medical field
Number of employees	~500	~250
Department at the time of purchase	Engineering / Process Analyst	Project Engineering / Mechanical Designer
Year of acquisition of Additive Technology	2016/2	2017/2
Duration of the acquisition process	6 months	3 months
Time of work in the field of Additive Manufacturing	2 years	1,5 year

Source: The Authors (2020).

Although the companies of both interviewees work in different segments, they worked in the same department in their companies and have practically the same experience in the area of Additive Technologies. It is noted that, in both cases, the decision-making process was alike (3~6 months).

Regarding Interviewee 1, through the questionnaire, some aspects were identified, such as: the department that Interviewee 1 worked was focused on the development of tools for plastic injectors, with this, additive manufacturing equipment was used exclusively for the development of new products or tests, i.e. prototypes. This aspect is evidenced in the following part "[...] *as it is a plastic industry, it has many components that have snap-fit system* [...]. *Then, basically it is used for developing new products and dimensional changes and design changes*."

As for the decision of the needs to acquire AM equipment, it can be divided into three factors, they are: presentation of prototypes/products, tooling cost and supplier of AM technology. In relation to the presentation and validation of the components, there was a constant difficulty in approving the products/prototypes through the computerized presentation to the board. Therefore, AM technology would ease the process, quoting a part from the interview, "[...] *having him physically we had the idea of trying to improve, this issue*" sell the idea better "*in simpler terms.*" Regarding the cost of tooling, each new product requires new tools that have a high acquisition value, as highlighted."*To manufacture a prototype direct at the factory, I had to stop a machine, dedicate a machine just for that. I'd have to make some investment in tooling, in mold, that's pretty high investments*". So AM technology would enable testing manufacturing without this cost of tooling development.

As concerns to the competitive criteria, the speed criterion obtained greater prominence. Due to the time of development of new tools for new products, the development lead time was long. For this reason the department was constantly asked harshly on deadlines by management. The return that AM technology brought to the company was highlighted during the interview:

> *For example, if I prototype there in the Engineering department, I can do it overnight, if not in the same day – depending on the part. When we had it outsourced done, in addition to having the cost, to buy this prototype, they had all those bureaucratic issues, making a purchase order, developing supplier, delivering time of the supplier* (10, 15, 30 days).

Finally, the competitive quality, flexibility and cost criteria were not considered important, because the company's focus was to develop prototypes. Being this aspect corroborated "*These issues of print quality or print size was not so important*." And, with respect to the cost criterion, it refers to a company's guideline in considering this criterion in all acquisitions.

As for Interviewee 2, through the questionnaire, some aspects were observed, such as: that it was focused on the development of prostheses and orthopedic devices, which, in a way, each case is a prototype. Therefore, the device should adapt the situation found in the patient's body.

In terms of the decision regarding the need to acquire AM equipment, it can be divided into two factors, which are: company/Interviewee 2 research and AM technology supplier. As for the research, during the interview, it is noticed that a greater domain of existing technologies and research on AM technology was acquired. As evidenced in the interview "*We compared standard manufacturing with Additive Manufacturing and came to a conclusion that the price and time of manufacture and* *process of each device would be less than the standard form of manufacturing.*" and "*At the moment we researched that some of our devices could be manufactured in this technology and applied in some manufacturing processes …*".

After all, the supplier for having a long-term relationship with the company also played a prominent role in the process of selecting additive technology. So, the indication of the technology, came from it as said "*The company already had a partnership that assist us in CAD and CAM, coming from this partnership, they indicated to us this technology.*".

As for competitive criteria, the most important was the quality criterion. This way, according to the interviewee, "*Because we work in the medical field and all prototypes have to be manufactured as close and accurate as the real*". Finally, competitive criteria speed, cost and flexibility were not considered important. Speed due to the fact that the company operates in the orthopedic area, such as surgical instruments. Where, "*accuracy and quality was what we sought, while speed ... was not necessary*". And, for the same reasons, cost and flexibility were not highlighted. The important thing for the company is to produce products or prototypes with quality and accuracy in order to avoid future problems.

Synthesizing for Interviewee 1, the need to acquire the equipment arose from the difficulty in approving new products with the company's board. The lack of visualization of the piece physically ready was a constant point of difficulty. For Interviewee 2, the need for acquisition arose from the realization that part of the components could be manufactured using Additive Manufacturing Technologies. In both situations, manufacturing and project development are contemplated in the relationship of the production system with the manufacturing system proposed by Black (1998). In addition to that, these investments are becoming a competitive weapon for the production system of these organizations, as stated by Skinner (1974).

Table 11 displays the usefulness found using IBM SPSS, version 25, to perform conjoint analysis based on the ordering of the cards performed by Interviewee 1.

Table 11. Utility - Interviewee 1.

Competitive Criteria	Utility Interviewee 1
Cost	1,0000
Flexibility	-3,0000
Quality	-1,0000
Velocity	5,0000

Source: The Authors (2020).

Based on the utilities obtained, it is verified that quantitative analysis is aligned with qualitative analysis (interviews x utilities). Since Interviewee 1 stated that the most important competitive criterion was speed and the lowest was flexibility. Cost and quality were not highlighted, cost because it is normally considered by the company in all acquisitions and quality, because it is a printer used only for prototypes, items such as accuracy and surface quality were not considered. Table 12 displays the usefulness found using IBM SPSS, version 25, to perform conjoint analysis based on the ordering of the cards performed by Interviewee 2.

Table 12. Utility - Interviewee 2.

Competitive Criteria	Utility Interviewee 2
Cost	0,3333
Flexibility	0,6667
Quality	6,0000
Velocity	0,3333

Source: The Authors (2020).

Based in the utilities obtained, it is verified that quantitative analysis is aligned with qualitative analysis (interviews x utilities). Interviewee 2, being from the orthopedic area, highlighted several times the importance of the component having quality (accuracy and surface quality), which is why the criterion speed and cost would not have so much importance for the application.

Finally, Kendall's Tau value was 0.817 (Sig. 0.001) for Interviewee 1 and 0.957 (Sig. 0.000) for Interviewee 2. Using as a basis a significance level of less than 0.050, the values found prove the reliability and internal validity of the research. For Interviewee 1, the model indicated MJ technology. For Interviewee 2, the model indicated FDM technology.

Referring to the Supplier, for model execution/evaluation, the Supplier chose to use a hypothetical scenario in which the MJ Technology printer is intended for rapid prototyping, where parts are used only for design and visual validation. That is, the characteristics of precision and surface quality linked to the competitive quality criterion should have a greater emphasis on this situation. Being manufactured with photopolymer material. Table 13 displays the usefulness found using IBM SPSS, version 25, to perform conjoint analysis based on the ordering of the cards performed by Supplier.

Table 13. Utility- Supplier.

Competitive Criteria	Utility Supplier
Cost	-0,6667
Flexibility	0,6667
Quality	6,0000
Velocity	0,3333

Source: The Authors (2020).

As observed, the criterion of greatest importance was quality. This result is aligned with the informed situation, where, the technology will be used for design and visual validation. Consequently, Kendall's Tau value was 0.857 (Sig. 0.001), using as a basis a significance level of less than 0.050, the values found prove the reliability and internal validity of the research. For the Supplier, the model indicated FDM technology.

Finally, with regard to the Specialist, for execution / evaluation of the model, the specialist, chose to use a scenario in which he had worked/finished in the week when the evaluation of the artifact of this research was scheduled. The scenario was an MJ Technology printer used in a metallurgical industry with the need to manufacture 4 similar prototype models for design and geometry visualization. Being the components manufactured with the polymer material. As requirements, a surface finish and affordable price were specified, that is, characteristics of the equipment linked to the competitive criterion quality and cost. Table 14 displays the utilities found based on the ordering of the cards made by the Specialist.

Table 14. Utility – Specialist.

Competitive Criteria	Utility Specialist
Cost	3,0000
Flexibility	1,0000
Quality	5,0000
Velocity	1,0000

Source: The Authors (2020).

As observed, the criterion of greatest importance was the quality followed by cost. Being this result aligned with the informed situation, since the informed requirements were affordable cost and surface finish. Finally, Kendall's Tau value was 0.873 (Sig. 0.001), using as a basis a significance level of less than 0.050, the values found prove the reliability and internal validity of the research. For the Specialist, the model indicated FDM technology.

6 Discussion

In this chapter, the results obtained with this research are discussed. Being presented in three stages, the first deals with the results of the decision-maker, the second of the supplier and the third of the specialist. Additionally, this section refers to the implementation of the general objective.

As shown in Chapter 5, for Interviewee 1, artifact recommended Jetting Material Technology (MJ). However, in the interview, it reported that the FDM technology was acquired by the company. Possible hypotheses for this difference are: lack of knowledge of MJ technology, prioritized criteria, search form, cost and technical assistance.

As for knowledge about MJ technology, in new contact, Interviewee 1 stated that he has no knowledge about this technology. However, analyzing the final products produced by the company, we highlight the applicability of this technology in the existing situation. This point contributed to show the influence that the supplier had on the acquisition process, since Interviewee 1 conducted few research on the existing AM technologies in the market. Additionally, it also illustrates the existing and subjective advantages that a particular supplier has when working with the company or by introducing the idea for a particular company.

Regarding the competitive prioritized criteria, as presented earlier during the decision-making process, the speed criterion was prioritized due to the needs of the sector in which the interviewee worked, which is why he obtained a significant usefulness in this criterion. Additionally, the cost was a variable considered by the company in all acquisitions, which is why it obtained a positive utility, however, low. When analyzing the Artifact database, it is verified that among the technologies that work with the indicated material, the MJ has the highest speed and intermediate acquisition value. That is, based on the utilities and characteristics of technologies, the Artifact is indicating the one that best suits the prioritized characteristics.

Regarding the cost factor, as stated in the interview, superficial research was conducted on other printers, but, as they had a higher acquisition value, they were not consulted/detailed. On this subject, follows a part of the interview: *"(...) Yes, it was evaluated, but by the cost subject we ended up not deepening this analysis (...) so we closed with the cheapest.*". This fact also contributed to illustrate the preference/influence that the supplier had during the decision-making process, since it was the only one contacted.

In the end, due to the fact that technical assistance is close by and the tests were accepted, Interviewee 1/ Company chose to acquire The FDM Technology. A part from the interviewee's speech that subsidizes the discussion: "[...] *then, technical assistance being close by was decisive as well.".*

As for Interviewee 2, the model recommended Fused Deposition Modeling Technology (MDF). After the decision-making process, company/Interviewee 2 opted for FDM Technology, the same indicated by artifact. Factors that contributed: knowledge of technology, prioritized criteria, comparison between technologies (traditional x additive) and technical assistance.

Unlike Interviewee 1, Interviewee 2/Company, conducted several research on AM technology that were budgeting. This know-how about the equipment contributed to the decision-making process regarding the acquisition of the equipment. This question is illustrated in the following part from the interview: "*We research the pros and cons of this new technology, because in our field in Europe it is common to use this technology.*".

Additionally, company/Interviewee 2 performed comparative analyses between Additive and traditional manufacturing technologies. It is noteworthy that for the application of the company, they concluded that due to the acquisition cost, time and manufacturing process, they should opt for an Additive Technology. This fact deals mainly with "prototypes", since, in the orthopedic area each case is different. In the words of Interviewee 2: "*We compared with standard manufacturing with Additive Manufacturing and came to a conclusion that the price and time of manufacture and process of each device would be less than the standard form of manufacturing*".

Another point that deserves to be highlighted, as evidenced in the conjoint analysis, is that the competitive quality criterion was valued by Interviewee 2. One of the reasons is due to the fact of acting in the orthopedic field, where it is important that there is precision at the expense of speed, for example. This item can be evidenced in several parts of the interview, such as: "Quality, because we work in the medical area and all prototypes have to be manufactured as close as possible to the real." Additionally, when analyzing the database, the technology that has the highest precision (contemplates competitive quality criterion) is the FDM.

Finally, it is worth highlighting three aspects. i) As well as Interviewee 1, Interviewee 2 basically dealt with a supplier/salesman partner. However, unlike Interviewee 1, he conducted research on AM technology that was in the process of acquiring. ii) Both interviewees highlighted the fact that technical assistance was close by. iii) Both answered that they did not miss having a tool to support decision-making regarding the selection of AM technologies, and information from the supplier was sufficient. Though, as evidenced, it is important to have other forms of information to support choice. This way avoiding the acquisition of a technology applicable to the situation, but not the most recommended (case of Interviewee 1), or research on AM technologies in unreliable sources (eventually, may have occurred in the case of Interviewee 2).

About the Supplier, the Artifact recommended Fused Deposition Modeling Technology (FDM). Nevertheless, it reported that Jetting Material Technology (MJ) was being considered for the illustrated situation. The Supplier's analysis in response to the result found: the parts produced with FDM technology have greater resistance, being recommended for situations where the prototypes/manufactured components will be submitted to functional tests; MJ technology has superior surface quality; FDM technology can be used in the exposed situation.

For the hypothetical situation tested, where, it is desired to validate design and visual, both technologies could be used, as stated by supplier. However, it is necessary to define which equipment characteristics in question would be most relevant to this application – superior surface quality or greater component strength. Because it is a hypothetical situation, the Supplier did not pre-define whether or not functional tests would be necessary (higher resistance) or only surface with superior finish, so the indication of the artifact could or may not be according to what is expected..

With regard to the superior surface quality of MJ technology, this data is compatible with the information contained in this research database. This contributes to evidence the accuracy of the information collected in the literature review, since this criterion was committed exclusively by the information obtained through the academic articles.

Finally, as for the Specialist, the Artifact recommended Fused Deposition Modeling Technology (FDM). Despite this, it reported that Material Jetting Technology (MJ) was being considered for the actual situation explained. The expert's analysis in response to the result found: the FDM technology will only be presented to the client if the MJ technology does not meet the variable acquisition value; in this case, the customer is willing to invest more to obtain a product that provides better surface quality.

For the actual situation tested, it is intended to manufacture 4 similar prototype models for design and geometry validation, both technologies could be used, as stated by the Specialist. When analyzing the database and statistical results, it is concluded that the artifact is indicating the FDM technology because it has a greater accuracy in relation to the MJ, even the MJ with surface quality, the difference in relation to accuracy is expressive. Additionally, according to the database of this research, FDM technology has a 10% acquisition value lower than MJ technology.

However, the situation used by the Specialist indicated a point of improvement of the artifact for future work. In this case, as informed, the company that was acquiring the equipment had a preference for a technology that would enable a higher surface quality. This feature is met by MJ technology.

After all, however, even during the paired analysis, the “+1” was added due to the existence of surface quality, this action was not sufficient to impact the final result. Thus, it is suggested that future research contemplates the identification of the criterion of greater importance for the respondent. Thus receiving an extra weight that is able to correctly influence the final indication of the model. In this way, the model will have the ability, for example, to indicate an Additive Manufacturing technology that has surface quality over accuracy – if so, the decision-maker needs it.

Finally, it is concluded that the indication of the artifact is correct from a technical point of view. Nevertheless, in this case, the customer wants a superior surface quality to the detriment of other characteristics, which is why MJ technology was offered.

7 Final considerations

The general objective of this research was to propose a model to support decision-making based on the characteristics of additive technologies and competitive criteria for the selection of Additive Manufacturing technologies in production systems.

After the construction of the artifact, it was evaluated from three perspectives: decision-maker, supplier and specialist. For the decision-maker, the artifact was evaluated in two different situations; for Interviewee 2, the indication was according to the acquired technology and the criteria that stood out were evidenced in the interview. In Interviewee 1, the indication was different from the technology acquired, however, as evidenced in the interview, the indicated technology was aligned with the criteria highlighted in the interview. Where, it was concluded that the artifact was correct, however, among the reasons highlighted above, it highlights the possible interference of the supplier/seller and the lack of research on the part of the organization/Interviewee 1. And, both from the perspective of Supplier and Specialist, the artifact indicated the technology applicable to the situation in question. Based on the final comments of the Supplier and Specialist, two works were generated for future research to be explained at the end of this section. Thus, in the three tested optics, the artifact worked correctly.

The research generated other contributions to the academic and/or business environment. The first contribution refers to the reduction of the gap in the literature and organizations regarding the comparability between technologies and research in the area of selection of additive technologies. As evidenced, this lack of information dificults the selection process in organizations. (Gokuldoss et al., 2017; Park & Tran, 2017; Rao & Padmanabhan, 2007). Additionally, the set of specifications and guidelines gathered also contributed to the increase of technical information available to the scientific community. In addition, this model is able to capture the overall structure of reality to ensure its usefulness, an important item for Design Science Research (Collatto et al., 2018; Dresch et al., 2015).

The second contribution is aimed at organizations. This research linked the competitive criteria at the time of the selection of additive technology, making the company's strategy related at the time of decision-making. Therefore, organizations will be able to maintain or achieve competitive advantages, considering a way to differentiate themselves from competitors. (Hum & Leow, 1996; Manzini et al., 2004; Pacheco et al., 2014; Slack & Lewis, 2009; Thürer et al., 2014).

The third contribution refers to decision-making. The artifact aims to support decision making. As pointed out during this research, each AM technology has advantages and disadvantages that can be more or less adequate according to the productive system needs under analysis. And, through competitive criteria prioritization, an indication of the technology to be used is obtained, thus reducing the conflicts of choice between the characteristics of the technologies. According to Salchev (2016) and Dolan (2008), decision-making is a complex process and part of people have difficulty making decisions when there are tradeoffs.

The fourth contribution refers to the impacts of a misacquisition. When using the artifact, you eliminate the risk of making an acquisition erroneously. Thus, productivity loss, increase in process time, quality, cost of reinvestment, non-compliance with market requirements, among other losses cited by Goldberg (2016) and McKnight (2016).

In addition to the contributions, the research also presented limitations. The first limitation was the non-consideration of the technical specifications of the materials. Each material has distinct specifications such as hardness, flexibility, ductibility, tension resistance, abrasion, high temperatures, among other characteristics. However, as evaluated, it did not impact the final result. Nevertheless, the addition of this information in future research will contribute to increasing the artifact accuracy.

The second limitation refers to maintenance and operation costs. This research delimited that it would not be part of the scope, due to the assumption that organizations perform this analysis naturally before the acquisition. However, including these variables in future research will contribute to increased accuracy regarding the needs of the organization at the time of selection.

To overcome the limitations presented, the researcher suggests the execution of two future studies. The first refers to additional research on the raw materials used by Additive Manufacturing Technologies, where, among other results, a detailed database is obtained to be used in conjunction with this work. For the second, the research should seek to quantify the maintenance and operation costs of AM technologies and subsequently seek ways to integrate into this artifact, thus increasing its accuracy and level of detail.

Additionally, based on the evaluations performed together with the Supplier and the Specialist, two chances of future work were discussed. The first opportunity of a future work refers to the use of printer characteristics. As stated by the Supplier, taking as an example the speed criterion, it was suggested that it be worked on by yield. This is due to the fact that some technologies did not have a linear yield during the printing process. Because of this, it is suggested that a future research analyze the criteria used in this artifact from this perspective, to complement and, if necessary, increase the information on the database. Contributing to increase selection accuracy of the artifact.

The second hypothesis refers to the importance of printer characteristics. For example, this research defined that if there was surface quality, it would be summed up “+1” in the note assigned in the paired analysis. However, as evidenced in the situation of the Specialist, this criterion had a greater weight at the time of decision-making by the final customer. Thus, it is suggested that a future work, analyzing and complementing this research regarding the quantification of certain “key” criteria for organizations. Thus expanding the weight given to certain criteria to be identified and also contributing to increase in accuracy of the artifact.

Finally, it is understood that this research opens opportunities for other studies that refer to the proposition of aditive manufacturing technology selection model. Additionally, the work offers opportunity for new research to evaluate other competitive and/or selection criteria in the area of productive systems. It is also noteworthy, the easy applicability of the artifact proposed in organizations and the generalization of the constructive form of the model for application in other situations of tradeoffs.

References

3D Hubs. (2016). *What is 3D printing?* 3D HUBS. Retrieved in 2017, October 2, from https://www.3dhubs.com/what-is-3d-printing

3D Insider. (2017). *The 9 different types of 3D printers*. 3D iInsider. Retrieved in 2018, July 21, from https://3dinsider.com/3d-printer-types/

Additively. (2017a). *Binder Jetting (BJ).* Retrieved in 2017, December 13, from https://www.additively.com/en/learn-about/binder-jetting#read-advantages

Additively. (2017b). *Electrom Beam Melting (EBM).* Retrieved in 2017, December 13, from https://www.additively.com/en/learn-about/electron-beam-melting#read-advantages

Additively. (2017c). *Laser Melting (LM).* Retrieved in 2017, December 13, from https://www.additively.com/en/learn-about/laser-melting#read-advantages

Additively. (2017d). *Material Jetting (MJ).* Retrieved 2017, December 13, from https://www.additively.com/en/learn-about/material-jetting#read-advantages

Black, J. T. (1998). *O Projeto da Fábrica com Futuro.* Porto Alegre: Bookman.

Ben-Ner, A., & Siemsen, E. (2017). Decentralization and localization of production: the organizational and economic consequences of additive manufacturing (3D Printing). *California Management Review*, 59(2), 5-23. http://dx.doi.org/10.1177/0008125617695284.

Berman, B. (2012). 3-D printing: the new industrial revolution. *Business Horizons*, 55(2), 155-162. http://dx.doi.org/10.1016/j.bushor.2011.11.003.

Bikas, H., Stavropoulos, P., & Chryssolouris, G. (2016). Additive manufacturing methods and modeling approaches: A critical review. *International Journal of Advanced Manufacturing Technology*, 83(1–4), 389-405. http://dx.doi.org/10.1007/s00170-015-7576-2.

Bocklund, L., Hinton, B., & Morey, M. (2011). Optimizing technology selection. *Pipeline Articles*, 1-7. Retrieved in 2017, December 1, from http://www.contactcenterpipeline.com/CcpViewIndex.aspx?PubType=2

Borenstein, D., & Betencourt, P. R. B. (2005). A multi-criteria model for the justification of IT investments. *INFOR*, 43(1), 1-21. http://dx.doi.org/10.1080/03155986.2005.11732711.

Bott, R. (2014). Competitive capabilities among manufacturing plants in developing, emerging and industralized countries: a comparative analysis. *Igarss*, 43(1), 1-5.

Brunello, G., Sivolella, S., Meneghello, R., Ferroni, L., Gardin, C., Piattelli, A., Zavan, B., & Bressan, E. (2016). Powder-based 3D printing for bone tissue engineering. *Biotechnology Advances*, 34(5), 740-753. http://dx.doi.org/10.1016/j.biotechadv.2016.03.009. PMid:27086202.

Bustamente, L. M. G., Duarte, R. N., & Almeida, D. A. (2010). Proposta de seleção de fornecedores para indústria de autopeças baseado na aplicação do BOCR. In *Anais do XXX Encontro Nacional de Engenharia de Produção* (pp. 1-14). São Carlos: ENEGEP.

Calignano, F., Manfredi, D., Ambrosio, E. P., Biamino, S., Lombardi, M., Atzeni, E., Salmi, A., Minetola, P., Iuliano, L., & Fino, P. (2017). Overview on Additive Manufacturing Technologies. *Proceedings of the IEEE*, 105(4), 593–612. https://doi.org/10.1109/JPROC.2016.2625098

Chan, F. T. S., Chan, H. K., Chan, M. H., & Humphreys, P. K. (2006). An integrated fuzzy approach for the selection of manufacturing technologies. *International Journal of Advanced Manufacturing Technology*, 27(7-8), 747-758. http://dx.doi.org/10.1007/s00170-004-2246-9.

Chen, L., He, Y., Yang, Y., Niu, S., & Ren, H. (2016). The research status and development trend of additive manufacturing technology. *International Journal of Advanced Manufacturing Technology*, 89(9–12), 3651-3660. http://dx.doi.org/10.1007/s00170-016-9335-4.

Chennakesava Reddy, A., & Shamraj, V. M. (1998). Reduction of cracks in the cylinder liners choosing right process variables by Taguchi method. *Foundry Magazine*, 10(4), 47-50.

Chuang, M., Yang, Y. S., & Lin, C. T. (2009). Production technology selection: deploying market requirements, competitive and operational strategies, and manufacturing attributes. *International Journal of Computer Integrated Manufacturing*, 22(4), 345-355. http://dx.doi.org/10.1080/09511920802209066.

Cobb, B. D., & Clarkson, J. M. (1994). A simple procedure for optimising the polymerase chain reaction (PCR) using modified Taguchi methods. *Nucleic Acids Research*, 22(18), 3801-3805. http://dx.doi.org/10.1093/nar/22.18.3801. PMid:7937094.

Cochet, P. (2016). *From assembly line to digital thread: the factory of the future is here, and it's here to stay*. GE Reports do Brasil. Retrieved in 2017, December 1, from https://www.ge.com/reports/assembly-line-digital-thread-factory-future-stay/

Collatto, D. C., Dresch, A., Lacerda, D. P., & Bentz, I. G. (2018). Is action design research indeed necessary? Analysis and synergies between action research and design science research. *Systemic Practice and Action Research*, 31(3), 239-267. http://dx.doi.org/10.1007/s11213-017-9424-9.

Crump, S. (2016). *Manufatura aditiva: 20 anos de evolução na indústria*. Retrieved in 2017, December 9, from http://www.cadxpert.com.br/ideias/manufatura-aditiva-20-anos-de-evolucao-naindustria/

Delgado, J., Blasco, J. R., Portoles, L., Ferris, J., Hurtos, E., & Atorrasagasti, G. (2010). Fabio Project: development of innovative customized medical devices through new biomaterials and additive manufacturing technologies. *Annals of DAAAM & Proceedings*, 21(1), 1541-1543.

Dias, M., & Fensterseifer, J. (2005). Critérios competitivos de operações agroindustriais: um estudo de caso no setor arrozeiro. *Revista Eletrônica Da Administração*, 11(3), 1-28.

Ding, D., Pan, Z., Cuiuri, D., & Li, H. (2015). Wire-feed additive manufacturing of metal components: technologies, developments and future interests. *International Journal of Advanced Manufacturing Technology*, 81(1-4), 465-481. http://dx.doi.org/10.1007/s00170-015-7077-3.

Dolan, J. G. (2008). Shared decision-making - transferring research into practice: The Analytic Hierarchy Process (AHP). *Patient Education and Counseling*, 73(3), 418-425. http://dx.doi.org/10.1016/j.pec.2008.07.032.

Dresch, A., Lacerda, D. P., & Antunes, J. A. V., Jr. (2015). *Design science research*. Porto Alegre: Bookman.

Dresch, A., Veit, D. R., Lima, P. N., Lacerda, D. P., & Collatto, D. C. (2019). Inducing Brazilian manufacturing SMEs productivity with Lean tools. *International Journal of Productivity and Performance Management*, 68(1), 69-87. http://dx.doi.org/10.1108/IJPPM-10-2017-0248.

Ernst & Young GmbH. (2016). *How will 3D printing make your company the strongest link in the value chain? EY's Global 3D printing Report 2016* (pp. 1-26). Londres: Ernst & Young GmbH.

ExOne (2017). *What is Binder Jetting?* Retrieved 2017, December 13, from http://www.exone.com/Resources/Technology-Overview/What-is-Binder-Jetting

Fatemi, A., Molaei, R., Sharifimehr, S., Phan, N., & Shamsaei, N. (2017). Multiaxial fatigue behavior of wrought and additive manufactured Ti-6Al-4V including surface finish effect. *International Journal of Fatigue*, 100, 347-366. http://dx.doi.org/10.1016/j.ijfatigue.2017.03.044.

Ford, S. L. N. (2014). Additive manufacturing technology: potential implications for U. S. manufacturing competitiveness. *Journal of International Commerce and Economics (USA)*, 6, 1-35.

Ford, S., & Despeisse, M. (2016). Additive manufacturing and sustainability: an exploratory study of the advantages and challenges. *Journal of Cleaner Production*, 137, 1573-1587. http://dx.doi.org/10.1016/j.jclepro.2016.04.150.

GmbH, H. F. P. (2013). *Electron Beam Melting (EBM) - Metal 3D Printing*. Retrieved in 2017, December 13, from https://fit.technology/electron_beam_melting_en.php

Gökkuş, Ö., Yıldız, N., Koparal, A. S., & Yıldız, Y. Ş. (2017). Evaluation of the effect of oxygen on electro-Fenton treatment performance for real textile wastewater using the Taguchi approach. *International Journal of Environmental Science and Technology*, 15, 449-460.

Gokuldoss, P. K., Kolla, S., & Eckert, J. (2017). Additive manufacturing processes: selective laser melting, electron beam melting and binder jetting — selection guidelines. *Materials (Basel)*, 10(6), 1-12. http://dx.doi.org/10.3390/ma10060672. PMid:28773031.

Goldberg, B. (2016). *75% of employers have hired the wrong person, here's how to prevent that*. Retrieved in 2017, November 28, from https://resources.careerbuilder.com/news-research/prevent-hiring-the-wrong-person

Green, P. E., & Srinivasan, V. (1978). Conjoint analysis in consumer research: issues and outlook. *Journal of Consumer Research*, 5(2), 103-123.

Green, P. E., & Wind, Y. (1975). A new way to measure consumers' judgments. *Harvard Business Review*, 75404, 106-117.

Gross, B. C., Erkal, J. L., Lockwood, S. Y., Chen, C., & Spence, D. M. (2014). Evaluation of 3D Printing and Its Potential Impact on Biotechnology and the Chemical Sciences. *Analytical Chemistry*, 86(7), 3240–3253

Grynol, B. (2012). *Disruptive manufacturing - the effects of 3D printing*. Canada: Deloitte.

Hair, J. F., Black, B., Babin, B., Anderson, R. E., & Tatham, R. L. (2006). *Multivariate data analysis* (6th ed.). Londres: Pearson.

Hair, J., Rabin, B., Money, A., & Samouel, P. (2005). *Fundamentos de métodos de pesquisa em administração.* Porto Alegre: Bookman.

Hiemenz, J. (2007). Electron beam melting. *Advanced Materials & Processes*, 165(3), 45-46.

Holmes, L. R., Jr., & Riddick, J. C. (2014). Research summary of an additive manufacturing technology for the fabrication of 3D Composites with Tailored Internal Structure. *JOM - The Journal of The Minerals, Metals & Materials Society*, 66(2), 270-274. http://dx.doi.org/10.1007/s11837-013-0828-4.

Huang, S. H., Liu, P., Mokasdar, A., & Hou, L. (2013a). Additive manufacturing and its societal impact: A literature review. *International Journal of Advanced Manufacturing Technology*, 67(5–8), 1191-1203. http://dx.doi.org/10.1007/s00170-012-4558-5.

Hum, S.-H., & Leow, L.-H. (1996). Strategic manufacturing effectiveness - an empirical study based on the Hayes-Wheelwright framework. *International Journal of Operations & Production Management*, 16(4), 4-18. http://dx.doi.org/10.1108/01443579610114040.

International Organization for Standardization – ISO. (2016). *ISO/ASTM 52900: Additive manufacturing — General principles — Terminology*. Genebra: ISO.

Kara, N. (2013). Use of additive maufacturing technologi in aviation industry. *Engineer & the Machinery Magazine,* 54(636), 70-75.

Kc, B., Faruk, O., Agnelli, J. A. M., Leao, A. L., Tjong, J., & Sain, M. (2016). Sisal-glass fiber hybrid biocomposite: optimization of injection molding parameters using Taguchi method for reducing shrinkage. *Composites. Part A, Applied Science and Manufacturing*, 83, 152-159. http://dx.doi.org/10.1016/j.compositesa.2015.10.034.

Khaleeq uz Zaman, U., Siadat, A., Rivette, M., Baqai, A. A., & Qiao, L. (2016). Integrated product-process design to suggest appropriate manufacturing technology: review. *The International Journal of Advanced Manufacturing Technology*, 91(1-4), 1409-1430.

Kietzmann, J., Pitt, L., & Berthon, P. (2015). Disruptions, decisions, and destinations: enter the age of 3-D printing and additive manufacturing. *Business Horizons*, 58(2), 209-215. http://dx.doi.org/10.1016/j.bushor.2014.11.005.

Kim, S-Il., Lee, J-Y., Kim, Y-K., Hong, J.-P, Hur, Y., & Jung, Y-H. (2005). Optimization for reduction of torque ripple in interior permanent magnet motor by using the taguchi method. *IEEE Transactions on Magnetics*, 41(5), 1796-1799. http://dx.doi.org/10.1109/TMAG.2005.846478.

Kuei, C., & Madu, C. N. (2003). Customer-centric six sigma quality and reliability management. *International Journal of Quality & Reliability Management*, 20(8), 954-964. http://dx.doi.org/10.1108/02656710310493661.

Kuei, H., Lin, C., Aheto, J., & Madu, C. (1994). A strategic decision model for the selection of advance technology. *International Journal of Production Research*, 32(9), 2117-2130. http://dx.doi.org/10.1080/00207549408957062.

Lee, Y.-H. (2012). A fuzzy analytic network process approach to determining prospective competitive strategy in China: a case study for multinational biotech pharmaceutical enterprises. *Journal of Business Economics and Management*, 13(1), 5-28. http://dx.doi.org/10.3846/16111699.2011.620165.

Li, L. L. X. (2000). Manufacturing capability development in a changing business environment. *Industrial Management & Data Systems*, 100(6), 261-270. http://dx.doi.org/10.1108/02635570010301188.

Li, Q., Kucukkoc, I., & Zhang, D. Z. (2017). Production planning in additive manufacturing and 3D printing. *Computers & Operations Research*, 83, 157-172. http://dx.doi.org/10.1016/j.cor.2017.01.013.

Lindemann, C., Jahnke, U., Moi, M., & Koch, R. (2013). Impact and influence factors of additive manufacturing on product lifecycle costs. In *Proceedings of the 24th Solid Freeform Fabrication Symposium* (pp. 998-1009). Paderborn, Germany: Sffsymposium Texas University.

Lira, A. C., Gomes, M., & Cavalcanti, V. (2015). Modelo de alinhamento estratégico de produção – MAP : contribuição teórica para a área de estratégia de produção. *Produção*, 25(2), 416-427. http://dx.doi.org/10.1590/0103-6513.069911.

Mahalik, D. K., & Patel, G. (2010). Efficiency measurement using DEA and AHP : A case study on indian ports. *IUP Journal of Supply Chain Management*, 7(1 & 2), 34-48.

Mahamood, R. M., Akinlabi, E. T., Shukla, M., & Pityana, S. (2014). Revolutionary additive manufacturing: an overview. *Lasers in Engineering*, 27(3/4), 161-178.

Malhotra, N. K. (2012). *Pesquisa de marketing - uma orientação aplicada* (6. ed.). Porto Alegre: Bookman.

Malladi, A. (2017). 3D Metal printing technologies: A review. *IUP Journal of Mechanical Engineering*, X(1), 48-55.

Mançanares, C. G. S., Zancul, E., Cavalcante da Silva, J., & Cauchick Miguel, P. A. (2015). Additive manufacturing process selection based on parts' selection criteria. *International Journal of Advanced Manufacturing Technology*, 80(5-8), 1007-1014. http://dx.doi.org/10.1007/s00170-015-7092-4.

Manzini, R., Gamberi, M., Regattieri, A., & Persona, A. (2004). Framework for designing a flexible cellular assembly system. *International Journal of Production Research*, 42(17), 3505-3528. http://dx.doi.org/10.1080/00207540410001696023.

Mazzoli, A. (2013). Selective laser sintering in biomedical engineering. *Medical & Biological Engineering & Computing*, 51(3), 245-256. http://dx.doi.org/10.1007/s11517-012-1001-x. PMid:23250790.

McKnight, C. (2016). *Step-by-step is the best approach to a successful technology selection*. Digital Clarity Group. Retrieved in 2018, May 31, from http://www.digitalclaritygroup.com/step-step-best-approach-successful-technology-selection/

Mellor, S., Hao, L., & Zhang, D. (2014). Additive manufacturing: a framework for implementation. *International Journal of Production Economics*, 149, 194-201. http://dx.doi.org/10.1016/j.ijpe.2013.07.008.

Mentzer, J. T., & Flint, D. J. (1997). Validity in logistics research. *Journal of Business Logistics*, 18(I), 199-217.

Miltenburg, J. (2008). Setting manufacturing strategy for a factory-within-a-factory. *International Journal of Production Economics*, 113(1), 307-323. http://dx.doi.org/10.1016/j.ijpe.2007.09.001.

Mohagheghi, V., Mousavi, S. M., Vahdani, B., & Siadat, A. (2017). A mathematical modeling approach for high and new technology-project portfolio selection under uncertain environments. *Journal of Intelligent & Fuzzy Systems*, 32(6), 4069-4079. http://dx.doi.org/10.3233/JIFS-152510.

Montgomery, D. C. (2012). Design and analysis of experiments. *Journal Technometrics*, 48(1), 158. https://doi.org/10.1198/tech.2006.s372.

Mudge, R. R. P., & Wald, N. N. R. (2007). Laser engineered net shaping advances additive manufacturing and repair. *Welding Journal-New York-*, 86(January), 44–48. http://files.aws.org/wj/2007/wj0107-44.pdf%5Cnhttp://proxy.lib.ohio-state.edu/login?url=http://search.ebscohost.com/login.aspx?direct=true&db=iih&AN=23731179&site=ehost-live

National Research Council. (1995). *Improving the environment: an evaluation of the DOE's environmental management program*. Washington: National Academy Press. Retrieved in 2018, December 30, from http://www.nap.edu/catalog/5173

Nunes, F. D. L., Piran, F. S., Bortolini, F., & Antunes, J. (2015). Análise entre posicionamento estratégico, estratégia de produção clássicae estratégia de produção da Hyundai. *Espacios*, 36(3), 1-10.

Palermo, E. (2013). *What is Laminated Object Manufacturing?* Retrieved in 2018, February 26, from http://www.livescience.com/40310-laminated-object-manufacturing.html

Pacheco, D. A. J., Lacerda, D. P., Corcini, S. L. H., No., Jung, C. F., & Antunes, J. A. V., Jr. (2014). Balanceamento de fluxo ou balanceamento de capacidade? Análises e proposições sistêmicas. *Gestão & Produção*, 21(2), 355-367. http://dx.doi.org/10.1590/S0104-530X2014005000006.

Paris, H., Mokhtarian, H., Coatanéa, E., Museau, M., & Ituarte, I. F. (2016). Comparative environmental impacts of additive and subtractive manufacturing technologies. *CIRP Annals - Manufacturing Technology*, 65(1), 29-32.

Park, H.-S., & Tran, N.-H. (2017). A decision support system for selecting additive manufacturing technologies. In *Proceedings of the 2017 International Conference on Information System and Data Mining - ICISDM '17* (pp. 151-155). USA: ACM. http://dx.doi.org/10.1145/3077584.3077606.

Park, J., Tari, M. J., & Hahn, H. T. (2000). Characterization of the laminated object manufacturing (LOM) process. *Rapid Prototyping Journal*, 6(1), 36-50. http://dx.doi.org/10.1108/13552540010309868.

Park, R. (2017). *New additive manufacturing processes continue to emerge*. Disruptive Magazine. Retrieved in 2017, October 1, from http://www.disruptivemagazine.com/features/new-additive-manufacturing-processes-continue-emerge

Peleshenko, S., Korzhyk, V., Voitenko, O., Khaskin, V., & Tkachuk, V. (2017). Analysis of the current state of additive welding technologies for manufacturing volume metallic products [review]. *Eastern-European Journal of Enterprise Technologies*, 3(1 (87)), 42-52. http://dx.doi.org/10.15587/1729-4061.2017.99666.

Persons, T. (2015). *3D printing: opportunities, challenges, and policy implications of additive manufacturing: GAO-15-505Sp - Addictive Manufacturing Forum*. USA: GAO. Retrieved in 2018, December 30, from http://www.gao.gov/products/GAO-15-505SP

Pilipovic, A., Sercer, M., Stojanovic, I., Brajlih, T., Drstvensek, I., & Valentan, B. (2011). Laminate object manufacturing Vs. Fused deposition modeling - machine comparison. In *Annals of DAAAM and Proceedings of the International DAAAM Symposium*, (pp. 221-222). Vienna, Austria: DAAAM. http://www.scopus.com/inward/record.url?eid=2-s2.0-84904325260&partnerID=40&md5=f03c55947ae024c9d133a553cfd4200b

Piran, F. A. S., Lacerda, D. P., Camargo, L. F. R., Viero, C. F., Teixeira, R., & Dresch, A. (2017). Product modularity and its effects on the production process: an analysis in a bus manufacturer. *International Journal of Advanced Manufacturing Technology*, 88(5–8), 2331-2343. http://dx.doi.org/10.1007/s00170-016-8906-8.

Piran, F. S., Lacerda, D. P., & Camargo, L. F. R. (2018). *Análise e gestão da eficiência*. Rio de Janeiro: Elsevier.

Poh, P. S. P., Chhaya, M. P., Wunner, F. M., De-Juan-Pardo, E. M., Schilling, A. F., Schantz, J. T., van Griensven, M., & Hutmacher, D. W. (2016). Polylactides in Additive Biomanufacturing. *Advanced Drug Delivery Reviews*, 107, 228-246. http://dx.doi.org/10.1016/j.addr.2016.07.006. PMid:27492211.

Pucci, J. U., Christophe, B. R., Sisti, J. A., & Connolly, E. S., Jr. (2017). Three-dimensional printing: technologies, applications, and limitations in neurosurgery. *Biotechnology Advances*, 35(5), 521-529. http://dx.doi.org/10.1016/j.biotechadv.2017.05.007. PMid:28552791.

Rao, R. V., & Padmanabhan, K. K. (2007). Rapid prototyping process selection using graph theory and matrix approach. *Journal of Materials Processing Technology*, 193(1-3), 81-88. http://dx.doi.org/10.1016/j.jmatprotec.2007.04.003.

Redwood, B. (2017). *Additive manufacturing technologies: an overview*. Retrieved in 2018, December 30, from https://www.3dhubs.com/knowledge-base/additive-manufacturing-technologies-overview

Redwood, B., Schöffer, F., & Garret, B. (2017). *The 3D printing handbook : technologies, design and applications*. Amsterdam, The Netherlands: Coers & Roest.

Rojko, A. (2017). Industry 4.0 concept: background and overview. *International Journal of Interactive Mobile Technologies*, 11(5), 77-91. http://dx.doi.org/10.3991/ijim.v11i5.7072.

Royal Academy of Engineering. (2013). *Additive manufacturing: opportunities and constraints*. London: Royal Academy of Engineering. Retrieved in 2018, December 30, from http://www.raeng.org.uk/publications/reports/additive-manufacturing

Rüßmann, M., Lorenz, M., Gerbert, P., Waldner, M., Justus, J., Engel, P., & Harnisch, M. (2015). *Industry 4.0* (pp. 1-20). Boston: The Boston Consulting Group. Retrieved in 2018, December 30, from https://www.bcgperspectives.com/Images/Industry_40_Future_of_Productivity_April_2015_tcm80-185183.pdf

Rylands, B., Böhme, T., Gorkin, R., 3rd, Fan, J., & Birtchnell, T. (2016). The adoption process and impact of additive manufacturing on manufacturing systems. *Journal of Manufacturing Technology Management*, 27(7), 969-989. http://dx.doi.org/10.1108/JMTM-12-2015-0117.

Saaty, T. L. (1983). Priority setting in complex problems. *IEE Transactions on Engineering Management*, 30(3), 140-155. http://dx.doi.org/10.1109/TEM.1983.6448606.

Saaty, T. L. (1990). How to make a decision: the analytic hierarchy process. *European Journal of Operational Research*, 48(1), 9-26. http://dx.doi.org/10.1016/0377-2217(90)90057-I.

Salchev, P. (2016). Objectification of The Decision-Making in Health Technology Assessment (Multi-criteria approach). *Bulgarian Journal Of Public Health*, 8(2), 3–30. http://ncphp.government.bg/files/projects/BG_JURNAL_PH_2_2016.pdf

Schelly, C., Anzalone, G., Wijnen, B., & Pearce, J. M. (2015). Open-source 3-D printing technologies for education: bringing additive manufacturing to the classroom. *Journal of Visual Languages and Computing*, 28, 226-237. http://dx.doi.org/10.1016/j.jvlc.2015.01.004.

Sculpteo. (2017). *The state of 3D printing* (pp. 1-30). USA: Sculpteo.

Simon, H. A. (1996). The sciences of the artificial. *Computers & Mathematics with Applications*, 33(5), 130. https://doi.org/10.1016/S0898-1221(97)82941-0

Skinner, W. (1969). Manufacturing--missing link in corporate strategy. *Harvard Business Review*, 47(3), 136-145. http://dx.doi.org/10.1016/S0267-3649(00)88914-1.

Skinner, W. (1974). The focused factory. *Harvard Business Review*, 52(MAY), 113-121. http://dx.doi.org/10.1225/74308.

Slack, N. (2002). *Vantagem competitiva em manufatura - atingindo competitivadade nas operações industriais* (2. ed.). São Paulo: Editora Atlas.

Slack, N., & Lewis, M. (2009). *Estratégia de operações* (2. ed.). Porto Alegre: Bookman.

Srivatsan, T. S., & Sudarshan, T. S. (2015). Additive Manufacturing: Innovations, Advances, and Applications. In A. Gebhardt & J. S. Hötter (Eds.), *Additive Manufacturing* (01-444). Boca Raton, Florida: Carl Hanser Verlag GmbH & Co. KG. https://doi.org/10.3139/9781569905838.fm

Teixeira, R., & Lacerda, D. P. (2010). Gestão da cadeia de suprimentos: análise dos artigos publicados em alguns periódicos acadêmicos entre os anos de 2004 e 2006. *Gestão & Produção*, 17(1), 207-227. http://dx.doi.org/10.1590/S0104-530X2010000100016.

Teixeira, R., Lacerda, D. P., Antunes, J., & Veit, D. (2014). *Estratégia de produção: 20 artigos clássicos para aumentar a competitividade da empresa.* Porto Alegre: Bookman.

Thanki, S., Govindan, K., & Thakkar, J. (2016). An investigation on lean-green implementation practices in Indian SMEs using analytical hierarchy process (AHP) approach. *Journal of Cleaner Production*, 135, 284-298. http://dx.doi.org/10.1016/j.jclepro.2016.06.105.

Thomas, D. (2016). Costs, benefits, and adoption of additive manufacturing: a supply chain perspective. *International Journal of Advanced Manufacturing Technology*, 85(5-8), 1857-1876. http://dx.doi.org/10.1007/s00170-015-7973-6. PMid:28747809.

Thomas, D., & Gilbert, S. (2014). Costs and cost effectiveness of additive manufacturing - a literature review and discussion. *NIST Special Publication*, 1176, 1-77.

Thürer, M., Godinho, M., Fo., Stevenson, M., & Fredendall, L. D.. (2014). Small manufacturers in Brazil: competitive priorities vs. capabilities. *International Journal of Advanced Manufacturing Technology*, 74(9-12), 1175-1185. http://dx.doi.org/10.1007/s00170-014-6042-x.

Tran, A., Teich, T., Dürr, H., Trommler, U., & Duong, A. N. (2017). Technology-based assistance system of additive process chains for prototype manufacturing (TAGAP). *International Journal of Engineering*, XV, 25-28.

Tsai, M. J., & Wu, C. (2014). Study of mandible reconstruction using a fibula flap with application of additive manufacturing technology. *Biomedical Engineering Online*, 13(1), 57. http://dx.doi.org/10.1186/1475-925X-13-57. PMid:24885749.

Varotsis, B. A. (2017). *Material Jetting.* Retrieved 2017, December 13, from https://www.3dhubs.com/knowledge-base/introduction-material-jetting-3d-printing#what

Vartanian, K., & McDonald, T. (2016). Accelerating industrial adoption of metal additive manufacturing technology. *JOM - The Journal of The Minerals. Metals & Materials Society*, 68(3), 806-810. http://dx.doi.org/10.1007/s11837-015-1794-9.

Veit, D. R. (2018). *Impactos da manufatura aditiva nos sistemas produtivos e suas repercurssões nos critérios competitivos* (Tese de doutorado). Universidade do Vale do Rio dos Sinos – UNISINOS, São Leopoldo.

Veit, D. R., Lacerda, D. P., Camargo, L. F. R., Kipper, L. M., & Dresch, A. (2017). Towards Mode 2 knowledge production: analysis and proposal of a framework for research in business processes. *Business Process Management Journal*, 23(2), 293-328. http://dx.doi.org/10.1108/BPMJ-03-2016-0045.

Wang, Y. M., & Chin, K. S. (2009). A new approach for the selection of advanced manufacturing technologies: DEA with double frontiers. *International Journal of Production Research*, 47(23), 6663-6679. http://dx.doi.org/10.1080/00207540802314845.

Wheelwright, S. C. (1984). Manufacturing strategy : defining the missing link. *Strategic Management Journal*, 5(1), 77-91. http://dx.doi.org/10.1002/smj.4250050106.

Wing, I., Gorham, R., & Sniderman, B. (2015). *3D opportunity for quality assurance and parts qualification: additive manufacturing clears the bar*. (Deloitte Series on Additive Manufacturing). Canada: Deloitte. Retrieved in 2018, December 30, from https://dupress.deloitte.com/dup-us-en/focus/3d-opportunity/3d-printing-quality-assurance-in-manufacturing.html

Wong, K. V., & Hernandez, A. (2012). A review of additive manufacturing. *ISRN Mechanical Engineering*, 2012, 1-10. http://dx.doi.org/10.5402/2012/208760.

Yao, R., Xu, G., Mao, S. S., Yang, H. Y., Sang, X. T., Sun, W., & Mao, Y. L. (2016). Three-dimensional printing: review of application in medicine and hepatic surgery. *Cancer Biology & Medicine*, 13(4), 443-451. http://dx.doi.org/10.20892/j.issn.2095-3941.2016.0075. PMid:28154775.

Yasa, E., & Kruth, J. (2011). Application of laser re-melting on selective laser melting parts. *Advances in Production Engineering & Management*, 6(4), 259-270.

Zadpoor, A. A. (2017). Design for additive bio-manufacturing: from patient-specific medical devices to rationally designed meta-biomaterials. *International Journal of Molecular Sciences*, 18(8), 1-18. http://dx.doi.org/10.3390/ijms18081607. PMid:28757572.

Zhai, Y., Lados, D. A., & Lagoy, J. L. (2014). Additive manufacturing: making imagination the major limitation. *JOM*, 66(5), 808-816. http://dx.doi.org/10.1007/s11837-014-0886-2.

Appendix A1. Characteristics of additive manufacturing technologies.

Table A2. Database – Technologies Features.

		Technology								
		Material Jetting (MJ)	**Fused Deposition Modeling (FDM)**	**Binder Jetting (BJ)**	**Selective Laser Sintering (SLS)**	**Laminated Object Manufacturing (LOM)**	**Stereolithograph y (SLA)**	**Electron Beam Melting (EBM)**	**Selective Laser Melting (SLM)**	**Laser Engineering Net Shape (LENS)**
Characteristics	**Velocity**	34800000000 mm/h	0,00059 mm/h	16,65 mm/h	32 mm/h	1828800 mm/h	14 mm/h	28800000000 mm/h	0,0024 mm/h	76,2 mm/h
	Maximum size of prototypes	490 x 390 x 200 mm	406 x 355 x 406 mm	300 x 200 x 150 mm	340 x 340 x 600 mm	305 x 406 x 102 mm	380 x 380 x 250 mm	350 x 350 x 380 mm	420 x 420 x 400 mm	900 x 1500 x 900mm
	Precision	140,0 µm	50,0 µm	100,0 µm	175,0 µm	100,0 µm	100,0 µm	140,0 µm	150,0 µm	186,0 µm
	Layers Thickness	17,0 µm	400,0 µm	250,0 µm	400,0 µm	200,0 µm	100,0 µm	50,0 µm	100,0 µm	125,0 µm
	Price	$ 220,000.00	$ 200,000.00	$ 250,000.00	$ 250,000.00	$ 100,000.00	$ 250,000.00	$ 250,000.00	$ 250,000.00	$ 250,000.00
	Surface Quality	+	-	-	-	-	+	+	-	-

Source: The Authors (2020). **Note:** Regarding the criterion surface quality, obtained through the systematic review of the literature, for the classification “Advantage” the “+” sign was used and for “Disadvantage” the “-” sign was used.

Appendix A2. Interview questionnaire.

Table A1. Theoretical basis of the questionnaire.

Question	Goal	Theoretical basis
1) What is the company's segment / area of operation?	Interviewee and company profile	A “funnel” approach, where the questions start broadly and later, more detailed and specific questions start.
2) How many employees?		
3) In which sector of the company did you operate at the time of the acquisition? And in which position?		
4) In what year was the additive technology acquired?		
5) How long did the decision / purchase process take?		
6) Time in the additive manufacturing area?		
7) How was the need to purchase the equipment verified?	General questions in order for the interviewee to remember the decision-making and equipment acquisition process	
8) For decision making by one technology over another, was it considered a payback? Spare parts? Affordable technical assistance? History of equipment in other companies?		
9) Was a comparative analysis performed between certain AM technologies?	Questions related to specific goal	The round of more specific questions begins. These questions contributed to the analysis of the results obtained by the artifact.
9.1) If so, why were certain technologies compared?		
9.2) If not, why not?		
10) When selecting a particular technology for study, was it taken into account any characteristic of the production system?		
10.1) If yes, which one?		
10.2) If not, what were the criteria used to start the acquisition study?		
11) At the time of the purchase decision, which competitive criteria weighed more in the decision?	Questions related to the competitive criteria studied in this research and its definitions	
11.1) Why?		
11.2) Was characteristic X (related to the informed criterion) of the technology considered in this criterion?		
12) Which criterion was the least important?		
12.1) Why?		
12.2) Was the characteristic X (related to the informed criterion) of the technology considered in this criterion?		
13) Why were criteria XX and XX intermediate? (missing competitive criteria)		
13.1) Have characteristics XX, XXX, XXX, XXX been considered? In what way? (related to the informed criteria)		
14) After the acquisition, did the technology fully meet expectations?		
15) Have the needs of the production system been met?		
16) If not, what were the possible causes?		
17) Today, after using it, would you do any analysis differently during the purchase decision process?		
18) What technology was chosen?	Questions related to acquired technology and materiall	To verify that the result of the artifact is correct and its applicability to the interviewees.
19) What material is used?		
20) During the process, did you miss an external support methodology? Were your references exclusively suppliers of additive technologies?		

Source: The Authors (2020).

Artifact

Considering the competitive criteria presented above and their definitions, in addition to their relation with certain additive technologies characteristics. Sort the cards below in order to represent the situation experienced at the time of the deciding/purchasing process of the technology in question. **Exemplify dynamics. Display the cards:**

Choice Profiles

Card	Cost	Flexibility	Quality	Velocity
1	High	High	High	High
2	High	Medium	Medium	Medium
3	High	Low	Low	Low
4	Medium	High	Medium	Low
5	Medium	Medium	Low	High
6	Medium	Low	High	Medium
7	Low	High	Low	Medium
8	Low	Medium	High	Low
9	Low	Low	Medium	High

Source: The Authors (2020). **Note:** Before question number 11, submit the Table below.

Definitions and relation of competitive criteria with certain characteristics of Additive Technologies.

Competitive Criteria	Definition	AM Technology Feature	Relationship
Cost	Cost for acquisition.	Acquisition value	The smaller the better
Flexibility	The company's ability to adapt its products to customer needs or to an individual customer.	Maximum size of prototypes Layer thickness	The bigger the better The smaller the better
Quality	Offer products that are produced according to pre-established standards and low defect rate.	Precision Surface Quality	The bigger the better The bigger the better
Velocity	The company's ability to deliver products in the shortest possible time.	Velocity	The bigger the better

Source: The Authors (2020) based in (Ben-Ner & Siemsen, 2017; Ernst & Young GmbH, 2016; Kuei & Madu, 2003; Li, 2000; Mahamood et al., 2014; Thomas & Gilbert, 2014; Tran et al., 2017; Wheelwright, 1984; Wing et al., 2015; Zhai et al., 2014).

Appendix A3. Raw materials contemplated x additive technologies studied.

Table A4. Raw Materials x Additive Technologies.

MATERIALS	Material Jetting (MJ)	Fused Deposition Modeling (FDM)	Binder Jetting (BJ)	Selective Laser Sintering (SLS)	Laminated Object Manufacturing (LOM)	Stereolithography (SLA)	Electron Beam Melting (EBM)	Selective Laser Melting (SLM)	Laser Engineering Net Shape (LENS)	QTY MATERIALS
Nickel Alloy		X					X	X	X	4
Titanium Alloy		X					X	X	X	4
Polymer	X	X			X	X				4
Tool Steel		X						X	X	3
Photopolymer	X	X				X				3
Alloy Stainless Steel		X						X	X	3
Aluminum Alloy		X						X	X	3
Copper Alloy		X							X	2
Chrome-Cobalt Alloy							X	X		2
UV Cured Plastic / Heat Resistant / Gray	X					X				2
Polystyrene		X		X						2
Thermoplastic Polymer		X		X						2
Acrylic (Similar)	X									1
Synthetic Ceramic Sand			X							1
Rubber	X									1
Cellulose					X					1
Fiberglass		X								1
PET filament with Propylene glycol		X								1
Polymer filament with wood fibers		X								1
Polymer filament with copper particles		X								1
Polymer filament with Bronze powder		X								1
Cobalt Alloy									X	1
Refractory Alloy									X	1
Cast Metal						X				1
Nylon filled with Aluminum powder				X						1
Iron and Chromium Oxide			X							1
Polyamide				X						1
Polyamide with carbon fibers				X						1
Polycarbonate						X				1

Source: The Authors (2020).

Appendix A4. Choice profiles.

Table A3. Displays the options obtained after using the fractional method.

Card	Cost	Flexibility	Quality	Velocity
1	High	High	High	High
2	High	Medium	Medium	Medium
3	High	Low	Low	Low
4	Medium	High	Medium	Low
5	Medium	Medium	Low	High
6	Medium	Low	High	Medium
7	Low	High	Low	Medium
8	Low	Medium	High	Low
9	Low	Low	Medium	High

Source: The Authors (2020).